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Economic incentives and conservation: Crowding-in social norms in a groundwater commons

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ABSTRACT

Price-based interventions can be corrective where users extract from a common resource, but may also impact existing social norms, often crowding them out. In contrast, I find a pumping fee implemented by a group of irrigators in Southern Colorado effectively crowds-in pro-conservation norms, enhancing the financial incentive's impact. Using a unique, spatially oriented panel-data set of groundwater wells, I separate the direct role of increased pumping costs from the indirect effect transmitted through altered conservation norms. To quantify conservation behavior, I estimate how pumping at one well responds to pumping at nearby wells – using instrumental variables to address simultaneity bias – and interact that behavior with a difference-in-difference framework to assess the influence of the intervention. In the preferred specification, the fee directly accounts for approximately 74% of the reduced pumping and the remaining 26% comes from crowding-in conservation norms.

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1. Introduction

The "tragedy of the commons" describes the logic that the divergence between private and social incentives inherent in common-pool resources (CPRs) lead to their inevitable over-use (Hardin, 1968). However, despite the incomplete private property rights, many groups have curtailed over-use through local rules and norms (Ostrom, 1990). Rather than being guided solely by financial considerations, users are driven by social preferences, reciprocity, and moral concerns as well.

Still, economists often advocate for the use of economic incentives to induce more efficient behavior (Pigou, 1920). Economic based tools –taxes, subsidies, or tradable permits – provide greater efficiency than less flexible environmental regulations (Goulder and Parry, 2008). Accordingly, use of economic based tools are often considered and increasingly implemented. Generally, there has been a movement to adopt payments for environmental services (PES) to reward and encourage conservation by introducing financial incentives (Engel et al., 2008; Wunder et al., 2008).

Where social norms already provide some conservation, it would seem more modest economic tools could be introduced to bring outcomes closer to the social optimum. However, since the 1970s many scholars have drawn on psychology to suggest economic incentives interact with other motivations (Frey, 1994). Economic incentives may crowd-out or crowd-in

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non-financial factors that had been promoting pro-social behavior. If crowding-out occurs, the intervention exhibits a rebound effect in which the impact of the financial incentive is subdued – possibly to the point of a net decrease of the sought behavior – because the role of non-price factors is reduced. Whereas if crowding-in occurs, the intervention induces more of the sought behavior than a narrow comparison of pecuniary marginal costs and marginal benefits would suggest. The literature offers a wide range of explanations why the presence of economic incentives would change behavior beyond the alteration of relative prices: e.g. aversion to control, release from moral obligation, reduced recognition of being "good", and an update in the value of the behavior (Frey, 1994; Bowles, 2008; Bolle and Otto, 2010; Rode et al., 2014).

In this paper, I provide empirical evidence from a natural experiment that the use of economic incentives can in practice crowd-in conservation. I analyze the case of a groundwater extraction fee applied to irrigators in San Luis Valley (SLV), Colorado. Following the increased cost, irrigators substantially changed their behavior, including reducing groundwater pumping by an average of 30 percent, corresponding to an estimated price elasticity of −0.79 (Smith et al., 2018). Given that the median irrigation water demand price elasticity in the literature is −0.16 (Scheierling et al., 2006) and groundwater fees elsewhere have failed to yield reductions (Yang et al., 2003; Schuerhoff et al., 2013), the reduction in SLV is notably large. Therefore, it becomes important that this fee was the outcome of an internal process within a region that generally exhibits high levels of collective-action (Cody et al., 2015).

To assess how much of the reduction is attributable directly to the fee versus any indirect effect from crowding-in social norms, I combine a five-year panel of well-level pumping data with geospatial well characteristic data. For conservation based on social norms, I use spatial variation and consider the narrow but identifiable measure of how irrigators respond to pumping by their neighbors, a likely symptom of incomplete property rights. In order to address the simultaneity bias – that neighbors' pumping is a function of your pumping – I rely on the permitted flow to instrument for the neighbors' pumping. Finally, I establish the impact of the fee on this behavior by employing a difference-in-difference framework, taking advantage of the fact that only a subset of wells confronted the fee for a number of years. This allows me not only to identify the direct effect of the fee, but to also assess whether an indirect effect emerges by holding nearby pumping constant and testing whether irrigators pump relatively more or less in response following the intervention. I take this change in competitive pumping to capture a crowding effect induced by the fee-intervention. The results indicate that a majority of the reduction is due directly to the fee (74%), but also that a substantial portion of the reduction stems from pumping relatively less in response to nearby pumping (26%). Additional robustness checks bolster the claim that the reduction is related to above-ground shifts in norms and not beneath-ground changes in hydrological connections.

2. Background

2.1. Crowding

Titmuss (1970) first brought wide attention to the idea of crowding-out, suggesting the use of payments, rather than relying on free donations, actually reduces the number of people willing to provide blood for medical purposes. In a more convincing empirical design, Gneezy and Rustichini (2000) find that the introduction of fines at a day-care for late pickups led to increased tardiness among parents. Generally there is wide support that prices can interact with social norms – usually crowding them out – across a wide variety of activities (Deci et al., 1999).

Accordingly, there is skepticism that prices are always appropriate to induce conservation because, among other concerns, social norms towards conservation can be crowded out. For instance, Kerr et al. (2012) find that community members are less willing to attend a communal clean up when offered a small reward than when no financial incentive is mentioned. Rode et al. (2014) provide a review of the environmental related crowding literature. The evidence, primarily stemming from lab and field experiments finds some crowding-out in many cases. More generally, prices may be representative of externally imposed rules that can undermine group-norms. In experimental settings, development of social norms to foster cooperation and internal adoption of rules often outperform exogenously imposed regulations (Cardenas, 2000; Vyrastekova and Soest, 2003; Lopez et al., 2012).

The literature does recognize that prices can crowd-in pro-social behavior (Frey, 1994; Bolle and Otto, 2010). In these cases, the price may enhance self-esteem through recognition, provide a normative signal that the behavior is desired, or reduce pressure to act selfishly by forcing others to participate in pro-social behavior. Empirical evidence, however, is lacking within the environmental context. In CPR game field experiments Narloch et al. (2012), Rodriguez-Sickert et al. (2008), and Andersson et al. (2018) find prices may crowd-in conservation practices. Evidence of crowding-in, especially in an actual intervention in the real world, has been elusive.

2.2. Economics of groundwater extraction

When extracting water from aquifers, irrigators confront at least two externalities. Though recharge rates vary depending on physical characteristics, generally there is a user cost to extraction today: the foregone use of the water in the future (Koundouri, 2004a). When this scarcity rent is ignored, irrigators pump myopically based only on today's marginal costs and marginal benefits, extracting relatively too much. The second externality is of a spatial nature. Property rights to the overlying land do not fully define the property rights to underlying aquifer because of groundwater's lateral movements. Extraction at one well creates a cone of depression, attracting water from nearby wells subsequently lowering the water table, increasing

the marginal costs of extraction at nearby wells (Brozović et al., 2010; Guilfoos et al., 2013). Irrigators, recognizing the externalities, can behave strategically, pumping more before the neighbors' pumping lowers their own water level (Koundouri, 2004b; Brozović et al., 2010). Collectively, the process lowers the water table beyond the optimal level and imposes additional pumping costs. Notably, the externalities are not independent. Because the groundwater rights are not secure, irrigators have little incentive to consider the user cost, as it is not clear they will be able to capture the conserved water in the future and can instead only compete contemporaneously to lay claim to the water today.

It remains unclear whether irrigators respond in a strategic fashion. In general, empirical evidence based on observed pumping is lacking because extraction is often not measured or recorded. What studies have been conducted yield mixed results. Huang et al. (2013) report evidence of strategic pumping in China while Pfeiffer and Lin (2012) find evidence in Kansas. Savage and Brozović (2011), in contrast, find little support for such behavior in Nebraska. The differences may not only be on account of variances in hydrology across settings or social norms among irrigators, but also due to the econometric challenges of addressing simultaneity bias and spatial correlation of unobservable characteristics.

Meanwhile, the losses from unregulated pumping are expected to worsen over time. For one, the gains from optimal control are predicted to increase as groundwater becomes more scarce (Koundouri, 2004a). Furthermore, with population growth and increasing aridity, the expectation is that irrigators will increasingly rely on groundwater resources (Gleick, 2010; Taylor et al., 2013; Richey et al., 2015). The pattern may have already emerged, especially within the United States where annual groundwater depletion in the first decade of the new century has more than doubled the rates observed in the 1980s and 1990s (Konikow, 2013).

As exemplified by the recent Sustainable Groundwater Management Act in California, groundwater regulations are increasingly being debated and implemented in response to droughts and increased withdrawals. Where groundwater pumping impacts surface right holders, wells may be forced to shut down entirely because they are out of priority.[1] Controlling well density can make property rights to groundwater relatively more complete by reducing the interaction of competing cones of depression (Edwards, 2016). Similarly, requiring or subsidizing more efficient irrigation technology offers a potential way to reduce pumping. But both spacing requirements and adoption of more efficient technology can undermine conservation if irrigators use the gains to switch to a more water intensive crop, as they have over parts of the High Plains Aquifer (Peterson and Ding, 2005; Pfeiffer and Lin, 2014; Edwards, 2016). There are potential efficiency gains to implementing economic-based incentives for water use instead, such as the tradable pumping rights implemented in Nebraska to reduce compliance costs of pumping reductions (Brozović and Young, 2014), but generally few examples for groundwater conservation exist.

Like tradable permits, a pumping fee introduces a price and an incentive to reduce groundwater use. The theoretical appeal of inducing economic and technological efficiency has long been recognized in the groundwater setting and continues to be suggested (Brown and Deacon, 1972; Zilberman et al., 1997; Koundouri, 2004a). However, there are doubts about the effectiveness of a fee, especially since a fee leaves open-ended the reduction that will occur. Given work on the price elasticity of water demand, generally between −0.03 and −0.40, the change in pumping from a change in price is expected to be low, though some research, using panel data and instrumentation for endogenous crop choice, suggests that water demand may be more elastic, around −0.79 (Schoengold et al., 2006).[2]

Regardless, the sparse empirical analysis of actual fees, which may be more than a “marginal” price increase, has been equally pessimistic. Imposing a tax on water use was insufficient to induce conservation in both the Netherlands and China (Yang et al., 2003; Schuerhoff et al., 2013). In contrast, Smith et al. (2018) finds a 30 percent reduction following the implementation of the pumping fee in the SLV. It is this case that I analyze to assess whether the large decrease is completely attributable to the direct increase in costs, or in part due to social norms towards conservation that were enhanced by the fee.

2.3. San Luis Valley irrigation

Nestled between the Sangre de Cristos and San Juan Mountains in Southern Colorado, the SLV forms the largest intermountain park in the world at 8300 square kilometers (Weiler and Seidl, 2004). The aridity of the area requires farmers to supplement rainfall: historically over 95 percent of cropland has been irrigated. Dating back to 1852, irrigators relied on snowmelt from the surrounding peaks to supply water. An expansive system of surface water ditches, numbering over 400, continues to convey snowmelt today subject to supply and the prior appropriation doctrine.

Groundwater development began to complement the surface water sources around 1950. Spurred by relatively cheap energy, new sprinkler technology, and a series of drought years in the 50s, junior irrigators first installed wells to provide resilience. Soon, though, even senior water right irrigators developed wells to draw on the additional water; from 1950 to 1960, the region went from 808 wells to 2704. Expansion continued, though more slowly, through the 1970s when a moratorium was placed on any new large capacity wells. Roughly 3500 wells were built and remain in use today. The aquifer system is complex and it is not yet well understood how water moves around, but Bexfield and Anderholm (2010) provide an

[1] The prior appropriation doctrine allocates water during shortages based on date of first use. Because wells generally developed after surface water, they are the most junior under conjunctive management.

[2] See Koundouri (2004a) and Scheierling et al. (2006) for reviews of elasticities.

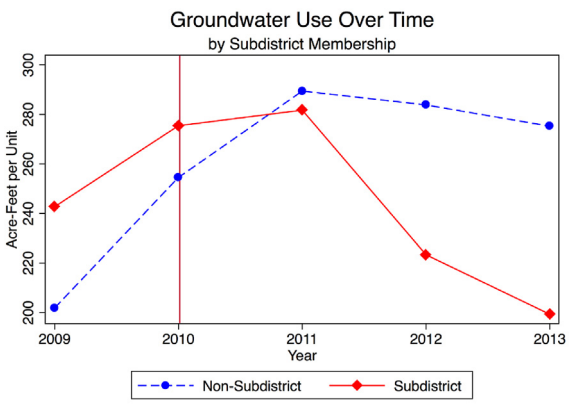

Fig. 1. Average groundwater extraction per unit by year measured in acre-feet. Left of the vertical line (maroon) are observations prior to intervention and to the right are after intervention Source: Smith et al., 2018.

overview of the hydrology. Notably, the aquifer exhibits high transmissivity (up to 2800 m^2/day), suggesting the groundwater migrates relatively freely.

Total storage of the aquifer is unknown but monitoring since 1976 provides a record for the change in storage. From 1976 through 2002, the aquifer remained stable in part due to an unusual string of wet years in the 1980s. The stability, however, was disrupted in 2002 when snowpack in April was only 6 percent of average. Because groundwater extraction remained unregulated, the irrigators simply pumped more. While not as severe as 2002, the first part of the new century was punctuated by many disappointing snowpack years. As a result, aquifer storage fell by over 1,000,000 AF from 2002 to 2013.[3]

Irrigators not only recognized their collective unsustainable groundwater extraction, but also faced the threat of state intervention, likely in the form of individual regulation. With a history of self-determination and successful collective-action, the irrigators chose to come up with a local solution (Cody et al., 2015). To make the endeavor manageable, the region was divided into six subdistricts, each tasked to create their own rules. Subdistrict #1 ("the subdistrict") began talks in 2006 and created a set of rules that went into effect in 2011. The irrigators chose an economic incentive to deter excess pumping, adopting a pumping fee to be set each year between $0 and $75 per AF. In 2011 the fee was set at $45 and then increased to the maximum $75 for subsequent years. Meanwhile, other subdistricts were not yet in operation, providing a valuable control group for empirical analysis. Given that subdistrict #1 irrigators apparently chose to impose a fee on themselves while others in SLV did not, it is worth considering the origins of the "unnatural" experiment and whether those outside of the subdistrict can be relied upon as a valid counterfactual (Besley and Case, 2000).

First, subdistricts are delineated based on hydrological connectivity, grouping wells more influential on one another and somewhat independent of other wells. Subdistrict #1, for instance, consists of contiguous irrigated land largely separated from other irrigated land to the north and the east, running up to the San Juan Mountains to the west, and following along the Rio Grande to the south. These firm geographical borders preclude irrigators from opting-in or –out of particular subdistricts. Second, those in subdistrict #1 moved first essentially because they were compelled to. Its size and proximity to the Rio Grande create a disproportionate (negative) impact on the numerous downstream senior surface-right claimants and Colorado's obligations to New Mexico according to the Rio Grande Compact. Meanwhile, calculating depletions caused by pumping requires significant technical resources, and developing subdistrict rules to address those depletions consumes significant legal resources. Due to a scarcity of technical and legal resources, combined with the importance of subdistrict #1 to the overall mission, the State Engineer dedicated its resources to subdistrict #1, requiring them to be first movers in SLV while others waited for their own technical and legal support.

Third, though each subdistrict creates its own regulations, there are factors that make a fee appealing and subdistrict #1 is not unique in thinking so. For instance, subdistrict #2 has now formed and enacted a pumping fee that can be as large as $150 per AF, twice the maximum rate as subdistrict #1 (RGWCD 2015). The four other subdistricts, based on early proposals and discussions, appear poised to adopt similar measures. The choice of a variable fee, in contrast to a non-revenue generating conservation tool, is at least partially related to the need to finance the purchase of surface rights to replace depletions in nearby streams. Though flat-fees could generate the needed income, the RGWCD – a consistent presence across all subdistricts – believes the variable fee can also reduce pumping.

Last, it is worth noting that not all irrigators within subdistrict #1 voluntarily signed up to pay the fee. The formation of the subdistrict required just over 50 percent of the irrigators (by number and by acreage) agreeing and RGWCD leaders state that

[3] AF-an acre-foot is the amount of water to submerge 1 acre in 1 foot of water, or 325,851 gallons.

meeting this was a struggle.[4] On net, despite the internal adoption of a pumping fee, the qualitative evidence suggests the adoption and timing of the fee in subdistrict #1 provides a convenient natural experiment vis-à-vis other subdistricts in SLV.

The impact of the intervention is important to understand since few price systems have been implemented for groundwater extraction. Fig. 1, showing annual pumping by farm units in SLV, provides suggestive evidence that the intervention has indeed reduced pumping within the subdistrict; the response is even greater if compared to pumping patterns outside of the subdistrict, but within SLV. In a more formal analysis, Smith et al. (2018) found that irrigators have reduced groundwater pumping per unit of land by 30 percent.[5] It is the overall reduction, arguably larger than the economic incentive would imply, that suggests the economic price may have also crowded-in conservation norms.

2.4. Crowding-in mechanism

In the case of groundwater extraction, the actors play both roles, both creator and recipient of external costs. In a simple framework, irrigators face a prisoner's dilemma: they are aware that conserving water is the social optimum, but they have an incentive to not conserve groundwater no matter the behavior of the other irrigators, at least in a static framework. However, because the game is repeated each year, many equilibriums exist and it is not apparent that the sub-optimum outcome is inevitable. But with a large number of extractors and no regulation, it is also not clear that they will avoid sub-optimum outcomes.

By adopting a price, the users have shifted up their marginal cost curves, meaning the payout structure has changed and users should pump less water on economic grounds. The crowding literature generally suggests that any conservation that occurred before may be crowded out. But most evidence of crowding-out stems from scenarios where market-mechanisms are introduced to a context previously working without financial dependencies. In contrast, resource users whose livelihood depends on the resource have been shown to respond positively to conditional cash incentives, with the increased conservation persisting even once the payments are ceased (Andersson et al., 2018). Not only have the users previously made explicit economic considerations for the use of the resource, but they also stand to gain economically from the conservation of the resource. Behavioral responses to the introduction of market-based regulations may differ in these contexts where the "inflictor" of the externality is also subject to the same externality such as road congestion, fisheries, and, the present context, groundwater exploitation (Heres and Lin Lawell, 2017). This is distinct from the realm of asymmetric moral or altruistic decision-making cases, such as picking up your child on time or volunteering blood donations.

In this context, the price may crowd-in conservation by acting as a commitment signal. Because the fee is internally imposed the adoption communicates to all users a collective commitment to achieve a better equilibrium (Vyrastekova and Soest, 2003). Further, for the conditional cooperators, the fee may erode their need for retaliation (by over pumping), creating a larger group of unconditional cooperators (Rodriguez-Sickert et al., 2008; Narloch et al., 2012; Rode et al., 2014).

3. Data

The Colorado Decision Support System (CDSS), a subset of the Colorado Division of Natural Resources, publicly provides the data utilized in this analysis. In addition to spatially oriented water structure data, structure-year water use measures gathered through bulk downloads from HydroBase constitute the majority of the data used for analysis.

Beginning in 2009, meters were installed on most wells in SLV and annual pumping records for 3472 wells are available from the CDSS, though the final sample for analysis based on complete records is reduced to 3060 wells. Pumping data for this and related research has been gathered and cleaned through the 2013 irrigation season. Identified by a unique water district identification number, the pumping data are linked to a number of well specific characteristics, including the permitted flow, well depth, and physical coordinates. For groundwater height, I use monitoring wells throughout the region and interpolate height at each well in ArcGIS.[6]

As mentioned above, SLV irrigators rely on surface water as well. Allocation of the annual snowmelt is determined by the prior appropriation doctrine. The scope for irrigators to substitute to surface water in response to the fee is extremely limited due to over-appropriation, costs of trading, limited storage reservoirs, and the use-it-or-lose-it component of water rights.[7] More surface water, however, may lead to a decrease use of groundwater. Accordingly, for each year I have collected data on

[4] Unfortunately, I am unable to distinguish those that signed the petition from those that did not, which would have provided a valuable dimension of heterogeneity amongst neighbors.

[5] In addition, the study found that irrigators have shifted away from flood irrigation, and, in contrast to technology adoption absent increased marginal costs, they have also shifted away from alfalfa production towards crops demanding less water.

[6] Some wells are outside of the interpolation making the number of observations slightly smaller.

[7] Only 0.7 percent of surface ditch water rights in SLV have appropriation dates during the sample period (2009–2013), representing a mere 0.2 percent of all ditch water rights by volume. Trades across ditches are infrequent, though unobserved reallocations within ditches are more prevalent. However, ditches primarily lay completely within or beyond the subdistrict border, so these transfers would not yield net gains of water in the subdistrict. In terms of storage, while SLV has 7 percent of the Colorado's water rights measured by flow, they have only 3 percent of the storage rights, suggesting a relative lag in storage development compared to Colorado as a whole. (Colorado Information Market Place Data, Water Right Net Amounts, was utilized to calculate these numbers https://data.colorado.gov/browse?category=Water). According to the National Inventory of Dams, 13 dams for irrigation were constructed in SLV, 8 of which prior to 1920 and the last one in 1978. However, only 16 percent of SLV's storage is found in the counties that the subdistrict covers. Furthermore, actual storage levels in SLV have been around 26 percent of capacity in recent years, generally indicative of a surface water shortage.

Table 1
Summary statistics.

Variable	Obs	Mean	Std. Dev.
Pumping (AF)	15,239	137.22	130.08
Neighbor Pumping			
.25 Miles	15,239	1027.23	750.96
1 Mile	15,239	4241.54	2756.22
2 Miles	15,239	8346.81	5308.27
3 Miles	15,239	12,230.23	7732.55
Own Nearby Pumping			
.25 Miles	15,239	54.82	98.74
1 Mile	15,239	71.63	162.86
2 Miles	15,239	77.78	204.49
3 Miles	15,239	80.87	240.90
Permit Flow (CFS)	15,239	2.44	1.81
Subdistrict 1	15,239	0.70	0.46
Pumping Fee	15,239	27.17	33.34
Surface Water	15,239	170.40	404.29
Parcels Served	15,239	1.62	1.34
Irrigated Acreage[a]	15,239	80.50	63.39
Sprinkler[a]	15,239	0.85	0.33
Well Depth	15,239	212.97	308.85
Groundwater Height	14,794	7608.24	59.88

Note: Data summary for variables and observations used in the main analysis. AF = acre-feet; CFS = cubic feet per second.
[a] Indicates parcel level data. Wells with multiple parcels are aggregated by summing (Irrigated Acreage) or averaging (Sprinkler).

the total acre-feet diverted by each surface ditch. Division within a ditch among parcels is unobservable, so I assume total supply is spread evenly across the land. As a matter of fact, the average surface diversions declined both within and beyond the subdistrict during the sample period, with no discernable change at the time of intervention.[8]

The spatial nature of the data allows for the construction of additional and important variables. Primarily, I am able to calculate the distance between any two wells. By matching this to pumping records, I create a total pumping by nearby wells measure by summing all pumping within various radii. Further, I attempt to distinguish whether the nearby well is owned by the same owner or someone else.[9]

Table 1 provides summary statistics for the variables and observations in the main analysis. Over the entire period, wells pump 137 AF of groundwater per year on average. Furthermore, the configuration is relatively dense. Within 0.25 miles of a well, 1024.69 AF of water is extracted by others' wells each year. On average, 7.3 wells owned by others are within this range. This density is much greater than on the Ogallala aquifer where Pfeiffer and Lin (2012) report only 0.6 wells within 0.5 miles on average.

Decreed rate of flow for a well comes from permit data and is denominated in cubic feet per second; the average permitted flow is 2.44 CFS. This amount is fixed for the well and does not vary over time. The subdistrict indicator variable is 1 for 70 percent of the sample, meaning more wells are observed within the subdistrict (2149/year) than outside (900/year). Well depth, measured in feet below surface, is 212.96 feet, but highly variable. Sprinkler technology is dominant, accounting for 85 percent of the wells. Last, groundwater height is on average 7608.32 feet above sea level (the valley floor is 7700 feet on average).

4. Preliminary empirical exploration

4.1. Influence of pumping on groundwater height

Because aquifers differ it is important to understand the extent of local lateral flow empirically: How much does pumping by well i impact the groundwater height at well i, and how much does nearby pumping do the same? This provides some sense of how incomplete the property rights are over the groundwater. Accordingly, using OLS, I estimate the following equation:

[8] The averages can be seen in Fig. A1 of the Appendix. The trends appear similar throughout the sample and there is no statistical significant change found in an (unreported) difference-in-difference regression.

[9] Without data on current ownership, I rely on observational data and an iterative grouping process, creating farm units based on linking wells across all shared parcels and shared wells. The process is unlikely to produce many false positives, but will under identify farm units where parcel-well combinations are one-to-one. Therefore some "own" pumping remains attributed to neighbors. If owners are more likely to consider externalities imposed by their pumping at one well on another of their wells, the error will lead to an underestimate of pumping in response to neighbors' pumping.

Table 2
Change in groundwater height.

VARIABLES	(1)	(2)	(3)	(4)
	GW Depth	GW Depth	GW Depth	GW Depth
Own Pumping	−0.00361***	−0.00357***	−0.00362***	−0.00368***
	(0.000604)	(0.000599)	(0.000601)	(0.000602)
Neighbor Pumping	−0.000550***	−0.000194***	−0.000108***	−7.73e-05***
	(5.29e-05)	(1.33e-05)	(6.62e-06)	(4.49e-06)
Own Nearby Pumping	−0.00128**	−0.000360	−8.08e-05	−1.34e-05
	(0.000576)	(0.000378)	(0.000247)	(0.000179)
Constant	6.948***	7.148***	7.204***	7.238***
	(0.372)	(0.375)	(0.373)	(0.375)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	14,674	14,674	14,674	14,674
R-squared	0.094	0.095	0.095	0.095

Note: Dependent variable is change in groundwater height from year t-1 to t at well i in year t. Well pumping is AF pumped at well i in year t. Neighbor pumping and own pumping are cumulative pumping within the specified range. Year fixed effects and surface water inflow are suppressed. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

$$\Delta GWH_{it} = \beta_1 W_{it} + \beta_2 \sum_{j\in(0,ub)} W_{jt} + \beta_3 \sum_{s\in(0,ub)} W_{st} + \boldsymbol{\delta}'\boldsymbol{X_{it}} + \tau_t + \varepsilon_{it} \quad (1)$$

The dependent variable is the change in groundwater height from last year to year t. The right-hand variables of interest are pumping by various wells: W_{it} is pumping at the well itself, $\sum_{j\in(0,ub)} W_{jt}$ is cumulative pumping by wells in the radius defined by the upper bound (ub) but not owned by the same owner of well i, and $\sum_{s(0,ub)} W_{st}$ are those within the radius owned by the same irrigator. Additional covariates (vector $\boldsymbol{X}_{it}$) are limited to surface water availability as a measure of potential recharge. Year fixed effects (τ_t) are also included.

The results are presented in Table 2 where each specification utilizes a different range to define nearby pumping. Pumping an acre-foot at the well in question reduces groundwater height by about 0.0036 feet. Given that average pumping is 137 AF/year, this lowers groundwater by 0.50 feet over the year. Pumping an additional acre-foot by a well within 0.25 miles also lowers the water table, but by a smaller amount (0.00055 feet). Notably, this coefficient gets smaller as wells further and further out are added, indicating that closer wells are more readily able to capture water. And while the marginal effect of pumping nearby is smaller than pumping at the actual well, given the average aggregate amount of pumping within a quarter mile (1027.23 AF), the total effect of nearby pumping is larger, lowering the water table by 0.56 feet. The presence of such large effects indicates that property rights over groundwater are far from complete and the external costs may be large.[10]

4.2. Overall impact of the intervention

Before disentangling direct and indirect effects, I consider the overall impact of the fee. Conducting a difference-in-difference analysis similar to Smith et al. (2018) but at the well level produces similar estimates.[11] Reported in the Appendix (Table A3) the implied price elasticity is −0.71; each additional dollar of the fee yields an additional reduction of 0.93 acre-feet and an average total reduction of 63.54 acre-feet. [12] Notably, when the fee and the *subdistrict*·*Post* term are both included, there is a general effect of 20.37 fewer AF pumped after the intervention and additional reductions of 0.66 AF/$ per dollar of the fee. This suggests there is a non-financial component to the reduction, but I turn to the spatial heterogeneity to better identify the effects.

4.3. Spatial relationships

The response appears to exhibit some spatial patterns. For instance, in Fig. 2, I map the change in observed average pumping from the pre-treatment years to the post-treatment years within the subdistrict at each well. There appear to be

[10] When interacting the pumping measures with an indicator for subdistrict membership (results provided in Table A2 of the Appendix), the interaction terms are not generally statistically distinct, indicating that the connectivity is generally similar inside and outside of the subdistrict.

[11] $W_{it} = \alpha_1 + \alpha_2 \times Treatment_{it} + \alpha_3 \times Subdistrict_{it} + \boldsymbol{\delta}'\boldsymbol{\omega_{it}} + \tau_t + \delta_d + \varepsilon_{it}$ is the regression equation. The variables are as defined below for equation (2) and equation (4). Treatment takes the form of an indicator, the nominal fee amount, (both are included in one instance), or the log(fee+40) where 40 is taken to be the average pumping cost. An official of RGWCD, who is also an irrigator, estimated costs to range from $25-$55 per acre-foot in SLV.

[12] The reduction is large, but irrigators indicate that by reducing acreage or switching to a "green manure" rotation rather than growing another crop actually increases yields while reducing input costs (including water but also fertilizer and other inputs) and may even increase profits.

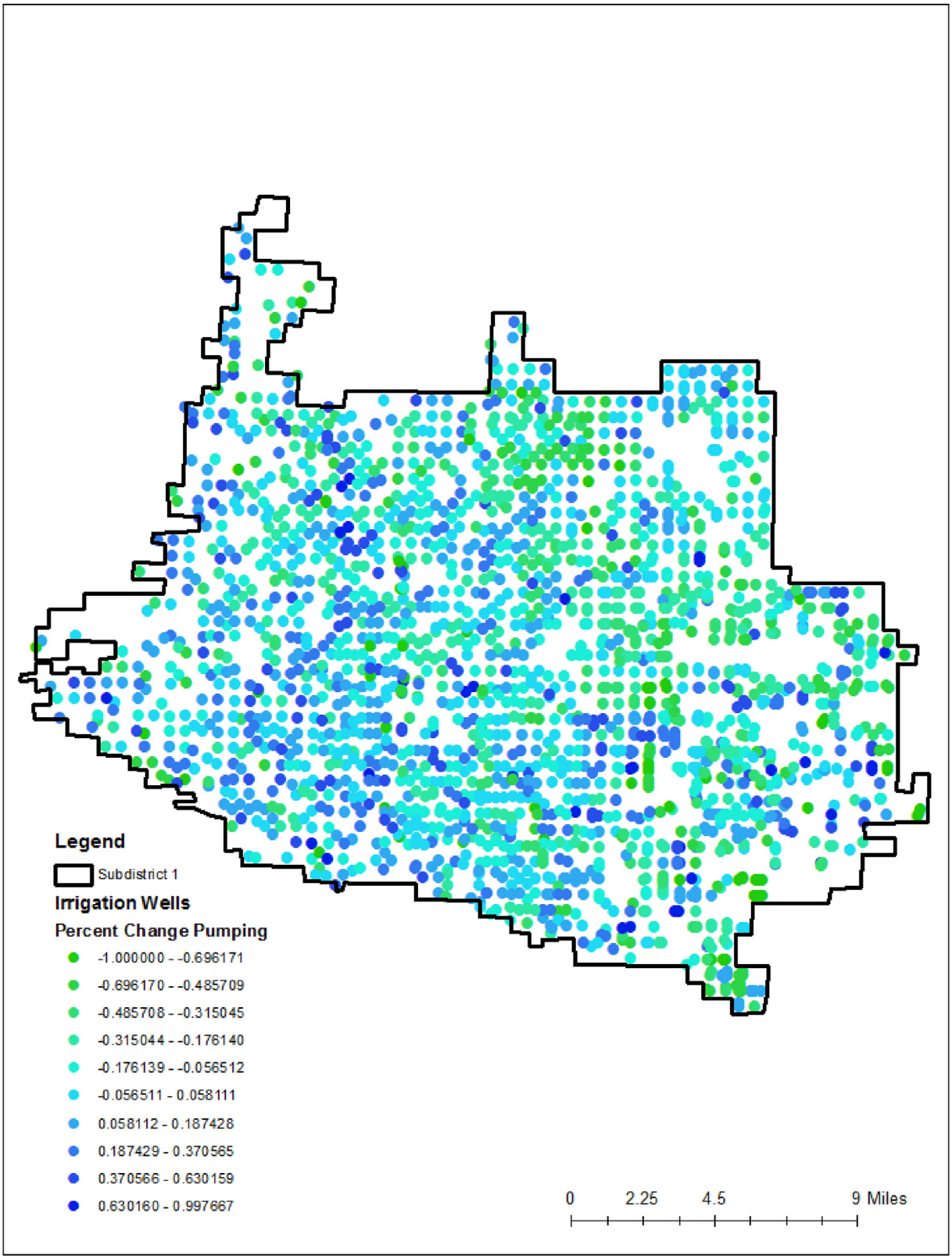

Fig. 2. Variation of change in pumping by wells within the subdistrict. Percent change is based on comparing annual average pumping at individual wells pre-intervention (2009–2010) to post-intervention (2010–2013).

Table 3
First stage example.

VARIABLES	(1)	(2)	(3)	(4)
	Neighbor Pumping	Neighbor Pumping	Neighbor Pumping	Neighbor Pumping
Neighbor Permits	19.77***	21.15***	21.66***	21.84***
	(0.301)	(0.238)	(0.212)	(0.199)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	15,239	15,239	15,239	15,239
R-squared	0.671	0.801	0.844	0.864

Note: The dependent variable is aggregated pumping by wells within the specified range of well i in year t. Neighbor permits is similarly defined but aggregating permitted flow. Additional controls are surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

clusters of wells that are similar in their changes. The Moran's I spatial correlation for this reduction is a statistically significant 0.128. In a regression framework with additional controls for well depth, permitted flow, and latitude and longitude, reported in Appendix A, Table A4, their remains a strong positive relationship between changes in pumping at well *i* and those around it.[13] Furthermore, the relationship is weaker as more distant wells are considered. This is suggestive that spatial factors are important. This specific result may not have to do with social-norms and changes in competitive pumping and could be driven by physical factors that lead some areas to be more responsive than others to a change in extraction costs.

A related question is whether irrigators in SLV pump relatively more in response to additional pumping by their neighbors. Before empirically testing for this behavior, it is important to consider whether it is reasonable to expect it. Specifically, to respond to nearby pumping requires knowledge of nearby pumping. Prior to 2009, fewer than 10 percent of SLV wells had meters. Even after 2009, the extraction was only reported annually after the season, not throughout the season. Still, it is reasonable that neighbors would have a general idea of their neighbors' water use. One, as shown above, nearby pumping does reduce groundwater levels, meaning data on pumping is physically transmitted. Second, irrigation technology, crop choice, and acreage planted are all highly observable and indicative of how much water will likely be used. For instance, potatoes, essentially sacks of water, are not forgiving to water shortages and will require a minimum amount of water-per-acre. The local farmers have a firm understanding of what it takes to grow a given acreage of a given crop in terms of the water needed. Third, neighbors can observe active sprinklers – when and how long they are running – updating the estimates created from the discrete planting choices.

In speaking to locals involved in groundwater pumping, one stated: "I think it is human nature to observe what your neighbors are doing and respond accordingly […] [n]eighbors have historically reviewed each other's practices, both in season and after the season."[14] Another irrigator noted that at their farm they are certainly aware of what the neighbors are doing with water and that those that appear to be liberally pumping water will almost certainly be subject of gossip at the coffee shop.[15] However, they both submit that the underlying motivation for individual water use is predominately financial.

To test whether SLV irrigators alter their own behavior in response to nearby pumping, I consider the following regression model:

$$W_{it} = \beta_1 \sum_{j \in (0,ub)} W_{jt} + \beta_2 \sum_{s \in (0,ub)} W_{st} + \boldsymbol{\delta}' \boldsymbol{\omega_{it}} + \tau_t + \delta_d + \varepsilon_{it} \tag{2}$$

In addition to the measures of nearby pumping, additional covariates (vector ω_{it}) include surface water supply,[16] number of parcels served, technology used, well depth, permitted flow, and latitude and longitude. In addition, year fixed effects (τ_t) and surface ditch fixed effects (δ_d) – with no surface water as the omitted group – are included. Estimating equation (2) by OLS, however, is problematic.[17] If well *j* is within the specified distance range from well *i*, then well *i* will also be in that distance range for well *j*. Estimation, therefore, is difficult because the simultaneity bias means $\text{cov}\left(\sum_{j \in (0,ub)} W_{jt}, \varepsilon_{it}\right) \neq 0$. In the spirit of Pfeiffer and Lin (2012), I adopt an instrumental variable approach, utilizing the permitted flow to provide exogenous variation for nearby pumping.

[13] The regression equation is $\Delta\overline{W_i} = \beta_1 \Delta \overline{\sum_{j \in (0,ub)} W_j} + \boldsymbol{\delta}' \boldsymbol{\theta_i} + \varepsilon_i$. That is, I regress the change in average pumping at well *i* on the total change in average pumping by those wells within a certain radius of well *i*. Additional covariates here ($\boldsymbol{\theta_i}$) include well depth, permitted flow, and latitude and longitude.
[14] Source is a water official and irrigator providing their thoughts through private email exchange in January 2018.
[15] This comes from a portion of a phone conversation between the author and an irrigator in January 2018.
[16] This includes interaction terms (pre- and post-treatment) with surface ditches that have a special decree for groundwater recharge as a beneficial use.
[17] OLS coefficient estimates for nearby pumping are presented in Table A5 of the Appendix. If taken literally, the estimates for the 0.25-mile range suggest 6.4 percent of annual pumping at a well is in response to nearby pumping.

Table 4
Permit dependence.

VARIABLES	(1)	(2)	(3)	(4)
	Permit	Permit	Permit	Permit
Neighbor Permits	0.00100	4.97e-05	−2.42e-05	−3.11e-05
	(0.00116)	(0.000315)	(0.000163)	(0.000112)
Own Nearby Permits	−0.119***	−0.0815***	−0.0680***	−0.0564***
	(0.0164)	(0.0137)	(0.0127)	(0.0119)
Constant	27.58**	29.10***	28.35**	28.68***
	(11.02)	(11.04)	(11.06)	(11.07)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	15,239	15,239	15,239	15,239
R-squared	0.336	0.332	0.330	0.329

Note: The dependent variable is the pemitted flow at well i. Neighbor permits is the aggregated total permitted flow of other wells within the specified range. Because permitted flow does not vary over time, coefficients are reported from a between-effects regressions. Additional controls are surface water supply, # of parcels served, technology used, well depth, latitude and longitude, and surface ditch fixed effects. Standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

4.4. Instrumenting for neighbor pumping

For the first stage I estimate equation (3) – specified below – by OLS, and then repeat for nearby pumping by wells owned by the same irrigator. I am then able to estimate a version of equation (2) using predicted values from the first stage.[18]

$$\left(\sum_{j\in(0,ub)} W_{jt}\right)_{it} = \alpha_1 \sum_{j\in(0,ub)} permit_j + \alpha_2 \sum_{s\in(0,ub)} permit_s + \boldsymbol{\delta}'\boldsymbol{\omega_{it}} + \tau_t + \delta_d + \rho_{it} \tag{3}$$

For the instrument to be valid it must sufficiently predict actual pumping (i.e. cov $\left(\sum_{j\in(0,ub)} permit_j, \sum_{j\in(0,ub)} W_{jt} \neq 0\right)$ and plausibly meet the exclusion restriction (i.e. cov $\left(\sum_{j\in(0,ub)} permit_j,\ \varepsilon_{it}\right) = 0$). Table 3 provides the results from estimating equation (3) directly. Though the main analysis below includes 5 instruments for the various interaction terms and "own pumping", in all cases it is the underlying permits that are utilized to instrument for the pumping, making the t-statistic and R-squared of this regression generally representative of the strength of the instruments. Across all radii the effect is similar: another cubic-foot per second permitted results in an additional 19.77–21.84 acre-feet being extracted. Furthermore, the t-statistic for the permitted flow is very large (~65). Using the aggregated permits to predict aggregated pumping at the 0.25 mile radius, the F-stat for its exclusion is around 2,300, well above the rules-of-thumb set out by Stock and Yogo (2005). Accordingly, the instrument's relevance is clearly established. Satisfying the exclusion principle cannot be as formally tested and requires more consideration.

In a simple thought experiment, the instrument seems viable; a neighbor's permitted flow should not impact my pumping other than through the impact it has on their actual pumping. This is particularly true because the permit is a flow, meaning a well could pump more or less volume by altering how long they are willing to pump. However, the permits themselves may not be entirely exogenous and the spatial distribution of permitted amounts may be correlated. In an ideal empirical setting, decreed flows would be randomly assigned. In reality, permits are determined predominantly by the maximum sustained yield during a pumping test. This means that permits are in part determined by the physical attributes of the area, which tend to be correlated in space. In general, the permits within and beyond the subdistrict do exhibit positive spatial correlation with a Moran's I of 0.347. Still, given the nature of the pumping tests, translation to permitted flow, and the econometric framework, the instrument justifiably satisfies the exclusion requirement despite the spatial correlation. More details are provided in Appendix B, but each point is touched upon here.

First, the tests themselves vary in quality. According to the Colorado State Engineer, a driller would determine the maximum sustained yield during a pumping test. Many times, the test was done with a test pump and not the actual pump to be used. Of those in the sample with yield data, 44 percent of the wells were tested after their first use while the remainder were tested prior to their first use, meaning at least half were likely tested with a pump other than the one eventually used. Furthermore, there was no set length of time for the tests, meaning some were longer than others, providing a more accurate measure. In perusing the original permits, I found tests that ran for 4, 5, 6, 8, and 12 hours. This variation in testing technique could result in variable yield measurements, even in the same vicinity of other wells that would in fact have similar yields.

Second, there appears to be some disconnect in translating yields (originally measured in gallons per minute) to decreed permitted flow rates (given in cubic feet per second). For wells with both variables available, I create a ratio of yield-to-

[18] For the actual IV estimations I do not manually run the first stage but utilize the ivregress command in Stata.

Table 5
Spatial relationship (IV).

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping	0.000489	−0.000213	−9.75e-05	−7.35e-05
	(0.00283)	(0.000728)	(0.000358)	(0.000242)
Own Nearby Pumping	−0.242***	−0.124***	−0.0980***	−0.0841***
	(0.0327)	(0.0280)	(0.0229)	(0.0213)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	15,239	15,239	15,239	15,239
R-squared	0.376	0.369	0.369	0.370
Adj. Partial Shea's R-Squared for Neighbor Pumping	0.521	0.690	0.752	0.779

Note: Dependent variable is pumping at well i in year t. Neighbor pumping is cumulative pumping within the specified range instrumented with cumulative permitted flow. Partial Shea's R-Squared reports the statistic for neighbor pumping. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

decreed flow. The simple unit conversion should result in a ratio close to 448 depending on rounding and indeed 75.12 percent of the sample fell between 447 and 450. However, the other wells varied widely around this figure. Evidence, presented in Appendix B, suggests there is no statistically detectable pattern for this variation including subdistrict membership, nearby permits, and location. Therefore, even beyond the variation in yield tests, the translation to permitted flow appears to introduce yet another random dimension. Furthermore, bolstering the relevance requirement for the instrument, there is no statistical relationship with observed pumping and the ratio, suggesting the decreed amount – not the test yield – is predicting the observed pumping.[19]

Third, to interpret the two-stage least square estimates as causal requires only that the permitted flow is random given the included covariates. To the extent that the concern is a correlation of nearby permits, I can empirically test for a relationship conditional on the covariates that are included in the main analysis. Table 4 provides the regression results for a between-effects analysis based on following equation:

$$permit_i = \delta_1 \sum_{j \in (0,ub)} permit_j + \alpha_2 \sum_{s \in (0,ub)} permit_s + \boldsymbol{\delta}' \overline{\boldsymbol{\omega}}_{\boldsymbol{t}} + \delta_d + \varphi_i \tag{4}$$

Of main concern is whether the aggregated permitted flows around well i ($\sum_{j \in (0,ub)} permit_j$) is predictive of the permitted flow at that well ($permit_i$). Permits within the neighborhood owned by the same irrigator enter the regression separately ($\sum_{s \in (0,ub)} permit_s$). The additional covariates ($\overline{\omega}_t$) are the same as defined for equation (3) except that time-varying components are averaged and permitted flow is not included since it is the dependent variable. Surface ditch fixed effects (δ_d) are included as well. The results strongly indicate that, conditional on the set of covariates, the permit at well i is not statistically related to aggregated nearby permits. Interestingly, there does exist some negative correlation with other wells owned by the same irrigator, suggesting these wells serve complementary roles to one another. And finally, if doubt of instrument validity remains, it is worth noting that I include permitted flow at well i as an additional control in the main analysis: the variation used to predict nearby pumping is beyond any average spatial correlation of permits. On net, despite the valid concern of the general spatial correlation of permits, the evidence available suggests permitted flow is a valid instrument for nearby pumping.

Returning to the spatial relationship of pumping patterns, I use two-stage least squares to estimate equation (2). Reported in Table 5, in contrast to OLS estimates, the coefficients across all radii are neither positive nor statistically significant. This average effect, however, may obscure any distinctive behavioral responses between those inside the subdistrict and those outside, and, more importantly, before and after the intervention.

5. Methods

In order to assess the direct and indirect impact of the intervention, I adopt a difference-in-difference framework. I utilize the wells outside of the subdistrict, but within SLV, as a counterfactual to proxy for any general trend and look at pumping before and after the intervention. The natural experiment follows Smith et al. (2018) but differs in two important ways. First,

[19] Given two wells with the same permitted flow, a higher yield would lead to a higher ratio. If the irrigator was ignoring the permit and operating based on the yield, then there should be a positive relationship between pumping and this ratio.

Table 6
Impact of economic intervention with spatial controls (IV).

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post × Subdistrict	−0.0178*	−0.00387	−0.00368***	−0.00264***
	(0.00962)	(0.00237)	(0.00127)	(0.000981)
Neighbor Pumping	−0.0154	−0.00211	−0.00140	−0.000426
	(0.0105)	(0.00306)	(0.00170)	(0.00137)
Neighbor Pumping × Subdistrict	0.0183*	0.00234	0.00139	0.000349
	(0.0107)	(0.00309)	(0.00173)	(0.00138)
Neighbor Pumping × Post	0.0156*	0.00306	0.00335***	0.00244**
	(0.00948)	(0.00234)	(0.00126)	(0.000972)
Own Nearby Pumping	−0.244***	−0.125***	−0.0978***	−0.0843***
	(0.0327)	(0.0281)	(0.0230)	(0.0215)
Post × Subdistrict	−3.863	−6.684	3.958	6.510
	(12.12)	(12.34)	(12.42)	(12.75)
Fee	−0.804***	−0.737***	−0.750***	−0.775***
	(0.154)	(0.153)	(0.153)	(0.153)
Constant	−793.9	−487.7	−547.3	−488.4
	(811.0)	(831.0)	(828.8)	(826.8)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	15,239	15,239	15,239	15,239
R-squared	0.387	0.380	0.379	0.381
Minimum Adj. Partial Shea's R-Squared	0.416	0.598	0.699	0.702

Note: Dependent variable is pumping at well i in year t. Neighbor pumping is cumulative pumping within the specified range instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

the analysis is conducted at specific wells rather than by land units. Second, and more importantly, I fully interact the difference-in-difference framework with neighbor pumping at various distances. The estimating equation is as follows:

$$W_{it} = \beta_1 Fee_{it} + \beta_2 \sum_{j\in(0,ub)} W_{jt} \times Subd_{it} \times post_t + \beta_3 \sum_{j\in(0,ub)} W_{jt} + \beta_4 \sum_{j\in(0,ub)} W_{jt} \times Subd_{it} + \beta_5 \sum_{j\in(0,ub)} W_{jt} \times post_t + \beta_6 \sum_{s\in(0,ub)} W_{st} + \beta_7 Subd_{it} + \beta_8 Subd_{it} \times post_t + \boldsymbol{\delta}'\boldsymbol{\omega_{it}} + \tau_t + \delta_d + \varepsilon_{it} \quad (5)$$

The direct effect of the financial intervention is captured by β_1 while β_2 is the estimated indirect effect as transmitted through a change in competitive pumping as captured by the triple interaction term: $\sum_{j\in(0,ub)} W_{jt} \times Subd_{it} \times post_t$. Critically, the β_2 coefficient captures the relative change in pumping per unit of water pumped by neighbors. In other words, if neighbors simply tend to change pumping by similar amounts (as indicated in Fig. 2) but still pump in the same proportion to one another as they did before, β_2 will be an insignificant zero. Only if *competitive* pumping changes should the model pick up an effect.

$Subd_{it}$ is equal to one if the well is part of the subdistrict while $Subd_{it} \times post_t$ equals one for those wells in 2011 and after. Accordingly, β_8 captures any average change in pumping related to the intervention independent of the fee amount and the relative magnitude of pumping around the well. The additional covariates (ω_{it}) are the same as in equation (2) and once again surface ditch fixed effects (δ_d) and year fixed effects (τ_t) are included with the latter absorbing the non-interacted $post_t$ indicator. Standard errors are clustered by well to be robust to autocorrelation and heteroskedasticity. Further spatial correlation of the errors was considered but the residuals in fact exhibit little spatial correlation.[20]

The estimation is done by two-stage least squares using permitted flows to instrument for nearby pumping. Rather than imposing a constant relationship between permitted pumping and nearby pumping, a separate instrument is used for each of the interactions. That is, rather than predicting nearby pumping by their permits once and then interacting the predicted values, I interact the permits and run four first-stage equations (and a fifth for nearby pumping by the same owner of well *i*) to predict the values. This way nearby irrigators are allowed to behave differently in response to their permitted flow across district borders and pre- and post-intervention. For the main results below in this multivariable and multiple instrument

[20] As an example, the average residuals when running the 1-mile specification have a Moran's I of just 0.052 (plot shown in Fig. A2 of the Appendix). Still, as a robustness check, I present the main results again in Table A8 of the Appendix with standard errors robust to spatial and temporal autocorrelation as well as heteroscedasticity (Conley, 2008; Hsiang, 2010). The standard errors and statistical significance is very similar.

Table 7a
Robustness checks (one mile).

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Acre Feet	Acre Feet	Acres	AF/Acre	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post × Subdistrict	−0.000828*	−0.00443*	−0.00205***	6.40e-05	−0.00926**	−0.000579*	−0.00847
	(0.000431)	(0.00250)	(0.000796)	(7.40e-05)	(0.00465)	(0.000347)	(0.0253)
Neighbor Pumping		−0.00297	−0.00187	0.000110	−0.00348	−7.92e-05	−0.000834
		(0.00312)	(0.00143)	(7.43e-05)	(0.00518)	(0.000179)	(0.00293)
Neighbor Pumping × Subdistrict	−0.000506	0.00328	0.00286**	−9.16e-05	0.00709	7.68e-05	0.0149
	(0.000793)	(0.00317)	(0.00144)	(7.37e-05)	(0.00516)	(0.000181)	(0.0286)
Neighbor Pumping × Post		0.00354	0.00179**	−7.54e-05	0.00429	0.000576*	0.00223
		(0.00247)	(0.000786)	(7.31e-05)	(0.00464)	(0.000346)	(0.00213)
Own Nearby Pumping	−0.215***	−0.121***	−0.144***	−0.00297***	−0.115***	0.000983	−0.0726
	(0.0298)	(0.0264)	(0.0156)	(0.000951)	(0.0279)	(0.00308)	(0.0471)
Post × Subdistrict		−9.787	16.11***	−0.766**	27.05*	−15.60	−113.6*
		(13.04)	(4.552)	(0.389)	(14.98)	(10.21)	(58.17)
Fee	−1.211***	−0.701***	−0.143***	−0.0139**	−0.712***	−0.672***	2.763***
	(0.0643)	(0.159)	(0.0373)	(0.00604)	(0.159)	(0.146)	(0.748)
GW Height		0.118					
		(0.0760)					
Constant	−6416***	−1341	−485.9	−18.53	−565.2	−43.08	−1732
	(993.0)	(1286)	(341.3)	(16.68)	(849.5)	(818.5)	(1108)
Subdistrict Sample	All	All	All	All	All	All	None
Robustness Check	Single Difference	GW Height	Extensive Margin	Intensive Margin	Lagged	Weights	Subdistrict 2
Observations	10,739	14,794	15,239	15,239	12,178	15,239	4500
R-squared	0.308	0.389	0.557	0.365	0.407	0.397	0.382
Minimum Adj. Partial Shea's R-Squared	0.739	0.601	0.598	0.598	0.183	0.536	0.400

Note: Dependent variable is irrigation at well i in year t; usually total acre-feet, but acres (specification (3)) and acre-feet per acre (specification (4)). Neighbor pumping is cumulative pumping within one-mile instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

context, I present partial Shea R-squared measures as the statistic for instrument strength (Shea, 1997), reporting only the minimum value for the four main instruments for brevity.

In order to interpret the resulting coefficient estimates as causal within the difference-in-difference framework, irrigators within the subdistrict would need to have shared a trend with those outside absent the intervention. Qualitatively discussed above, I focus here on the statistical support. Inherently untestable, often evidence of a similar trend pre-intervention is used to substantiate the assumption. Returning to Fig. 1, though subdistrict units pumped more on average in 2009 and 2010, the relative increase by both groups from 2009 to 2010 do appear similar. Evidence in Smith et al. (2018) established with statistical evidence that the pre-treatment trends were indistinguishable. However, for the current analysis it is important that both groups follow a similar trend in their relative behavior to nearby pumping. To test this assumption, I estimate equation (5) but only for 2009 and 2010, replacing $post_t$ with an indicator for 2010. Because this is pre-intervention, the relative change from 2009 to 2010 should be the same. Results are reported in the Appendix, Table A6, and show no distinguishable difference in the trend pre-intervention. Accordingly, it is reasonable to assume that they would have continued to do so.

6. Results

6.1. Main outcome

Regression results for equation (5) – with instrumental variables for nearby pumping – are reported in Table 6.[21] The estimates indicate that part of the total reduction is due to reduced pumping related to neighbors' pumping. The per-unit impact is largest for pumping within 0.25 miles, where subdistrict irrigators pump 0.0178 fewer AF per AF pumped within that range than they did before the fee and relative to the control group. Given average pumping characteristics, this would amount to 18.3 fewer AF pumped each year. This conservation is on top of the direct impact of the fee, which is reduced in magnitude slightly (to −0.804 AF/$) compared to the estimate without the spatial controls (−0.93 AF/$). The smaller impact of the fee is consistent with the spatial crowding-in component being picked up by the fee itself when the spatial variable is omitted.

[21] Table A7 of the Appendix provides estimated results by OLS for comparison. Given the interaction terms with the difference-in-difference framework, signing the bias is not unambiguous. The bias of the interaction term would depend on the direction and magnitude of the bias of the main effect as well as the interaction with post-intervention and subdistrict wells.

Table 7b
Robustness checks (one mile) continued.

VARIABLES	(8)	(9)	(10)	(11)	(12)	(13)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post × Subdistrict	−0.00376	−0.00778*	−0.00288	−0.00427*	−0.00349	−0.00450*
	(0.00236)	(0.00460)	(0.00248)	(0.00245)	(0.00243)	(0.00239)
Neighbor Pumping	−0.00207	−0.00103	−0.00183	−0.00173	−0.00167	−0.00165
	(0.00306)	(0.00304)	(0.00303)	(0.00307)	(0.00304)	(0.00305)
Neighbor Pumping × Subdistrict	0.00234	−0.0213	0.00691**	−0.000113	0.00220	0.00128
	(0.00308)	(0.0211)	(0.00338)	(0.00334)	(0.00315)	(0.00317)
Neighbor Pumping × Post	0.00305	0.00269	0.00299	0.00303	0.00300	0.00295
	(0.00233)	(0.00232)	(0.00232)	(0.00234)	(0.00233)	(0.00233)
Own Nearby Pumping	−0.120***	−0.0844*	−0.0847**	−0.126***	−0.113***	−0.102***
	(0.0281)	(0.0466)	(0.0368)	(0.0326)	(0.0393)	(0.0313)
Post × Subdistrict	−8.377	174.7**	−25.48*	17.28	−11.43	12.27
	(12.32)	(73.58)	(14.10)	(15.26)	(13.46)	(14.55)
Fee	−0.714***	−2.120**	−0.377**	−1.048***	−0.632***	−0.889***
	(0.153)	(0.957)	(0.173)	(0.187)	(0.163)	(0.166)
Constant	−516.7	−1152	−766.8	−323.3	−786.1	−458.5
	(835.6)	(1011)	(917.5)	(906.7)	(870.9)	(920.0)
Subdistrict Sample	Different Ditch	Same Ditch	Border	Inside	Low Externality	High Externality
Robustness Check	Ditch Membership		Neighbor Treatment		Externality	
Observations	14,674	5065	7536	12,203	10,000	9739
R-squared	0.383	0.373	0.377	0.395	0.403	0.379
Minimum Adj. Partial Shea's R-Squared	0.598	0.208	0.595	0.579	0.596	0.596

Note: Dependent variable is irrigation at well i in year t in total acre-feet. Neighbor pumping is cumulative pumping within one-mile instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Expanding the radius results in smaller coefficient estimates.[22] At three miles, the marginal reaction to nearby pumping is only −0.00264. The smaller point estimate is consistent with pumping further away being less influential; i.e. an acre foot extracted three miles away plays a lesser role in pumping behavior than an acre foot extracted just across the road. Given an average of 12,230.23 AF pumped in the three-mile range, reduction relative to nearby pumping within three miles is a 32.29 AF. The direct impact of the fee is estimated to be −0.706 AF/$. Over the course of the three years, the average fee is $65/AF, meaning a reduction of 45.89 AF can be attributed directly to the fee. The size of these effects suggests that the fee accounts for the largest portion of the reduction, 59 percent, but that the change in pumping response accounts for a non-negligible share, 41 percent. Admittedly large, this may overstate the role of the social norms, especially if it is only really close pumping that should be included and the expanded radii is forcing some of the effect to be attributed to the nearby pumping rather than the fee itself. When limiting the comparison to 0.25 miles or 1 mile and conducting similar back-of-the-envelope calculations, only 26 percent of the reduction is attributed to the spatial relationship while 74 percent comes from the fee.[23]

6.2. Robustness

While the main analysis provides evidence consistent with the intervention crowding-in conservation beyond the financial incentives, a series of robustness checks bolster these claims considerably. For brevity, I present only the results for the one-mile radius (Tables 7a and 7b), but the full tables for each are available in Appendix A (Tables A9–A18).

First, the main results are in part due to an apparent uptick in competitive pumping outside of subdistrict #1 after the intervention. Given that water levels continued to fall while crop prices continued to rise during this period, it is not unreasonable to suppose that absent the financial intervention, those within the subdistrict would have also increased their competitive pumping since common-pool issues are predicted to increase with scarcity of the resource (Koundouri, 2004a). Nevertheless, in specification (1), I remove the control group and test whether there is a reduction in absolute terms. Though smaller in magnitude, there remains a statistical reduction in pumping even without the control group for a reference point. Still, it is feasible that the reduction in pumping is not based on norms but that marginal pumping costs (unobserved) are increasing as pumpers nearby lower the water table. To assess whether the reduction stems from this physical connection

[22] The estimate for the 1-mile radius is statistically significant at the 10.2 percent confidence level.

[23] One reason to favor the 0.25-mile or 1-mile radius is that the total impact in both cases sums to 70 and 65 AF respectively, which is closer to the total reduction found in the simple difference-in-difference results reported in specification (1) of Table A3. The aggregate reduction using the 3-mile radius, in contrast, totals over 78 AF, a possible indication that the reduction is being overstated at this radius.

rather than an alteration of social norms, I add groundwater height as a control in specification (2). As expected, the coefficient on groundwater height is positive (higher levels increase pumping), but the crowding-in result remains and is actually strengthened.

The purview for alterations to water use within a season in response to neighbors' behavior may be small in scope because 1) water needs for a given crop and acreage planted may be stringent and 2) at best, behavior is based on an estimation of neighbors' pumping, rather than actual pumping with crop choice and acreage providing an early season indicator of intended use. Accordingly, I estimate equation (5) with alternative outcomes to explore adjustments made on the intensive margin (acre-feet per irrigated acre, specification (3)) and the extensive margin (irrigated acres, specification (4)). In direct response to the fee, irrigators respond on both margins. However, the effect of neighbors' pumping on irrigation choices is dominated by the extensive margin; irrigators do not reduce pumping per acre relative to nearby pumping, but they do reduce irrigated acreage. This alteration is largely made prior to active pumping, making it likely due to relative increase in pro-social behavior to compete less for the common-pool resource and not symptomatic of any within-season drawdowns that impact pumping costs of neighbors. Meanwhile, last years' pumping is recorded, meaning irrigators can observe actual pumping with a lag. Furthermore, irrigators have more time and latitude to alter their agricultural plans for the current year based on nearby pumping in prior years. Accordingly, in specification (5), I utilize nearby pumping from the prior year for the controls. The estimated change in competitive pumping is 2–3 times larger in magnitude for this specification.[24]

Next, I attempt to weight nearby pumping by hydrological conductivity in order to isolate the change in pumping that is related to the below-ground spatial externality in order to compare with the unweighted model which arguably captures the above-ground shift in norms. However, measures of hydroconductivity are not available for SLV, so I can only consider distance and height and the scaling becomes somewhat arbitrary.[25] With that caveat in mind, the results, reported in specification (6) do find a small reduction in competitive pumping but is significantly smaller in magnitude. This is consistent with the reduction in competitive pumping being driven more by norm-shifts above ground than changes in the actual incidence of the spatial externality.

As a placebo test, in specification (7), I remove subdistrict #1 wells completely and assign "treatment" to those wells that fall within subdistrict #2, which has also opted to impose a pumping fee but was not yet doing so during the sample period. There is no indication that competitive pumping reduced within subdistrict #2. This lack of change casts doubt that talk alone – the collaborative process independent of actually facing the fee – is sufficient to crowd in norms. That is not to say that the internal process is not crucial to bolstering the impact of the fee, but that the implementation of the regulation, if not a fee specifically, provides the mechanism to alter the conservation norms.[26]

To further test whether the changing spatial relationship to nearby pumping actually provides a proxy for a shift in social norms rather than some other physical or spurious relationship, I divide the subdistrict wells by the type of neighbors they have and run separate regressions to assess whether the effect differs, reported in Table 7b. First, researchers have found resource users with higher levels of initial trust are more likely to exhibit crowding-in of conservation with the introduction of financial incentives (Andersson et al., 2018). Others have explicitly found that trust and pro-social behavior are generally stronger among farmers that share irrigation systems (Tsusaka et al., 2015). Accordingly, I hypothesize that groundwater users that are already linked by a surface ditch organization will have greater levels of trust with one another and be more susceptible to crowding-in pro-conservation behavior. Therefore, I divide the subdistrict wells into those with nearby wells that also utilize the same surface ditch from those that have at least one nearby well within the given distance that does not share the same surface ditch.[27] The results are consistent that the decreased pumping stems from a shift in pumping norms. In specification (8), wells with neighbors from other ditches do not exhibit a statistical reduction in pumping related to nearby pumping. However, in specification (9), the subdistrict wells with only neighbors that are members of the same surface ditch do reduce their competitive pumping. The estimate is statistically significant and more than twice the magnitude of the point estimate in specification (8). If the change after intervention was related solely to physical connections underground, surface ditch membership, and the associated social capital, should not impact the change.

I also separate subdistrict wells by whether or not any well counted as a neighbor falls outside of the subdistrict borders.[28] If the effects are simply financial there should be no difference in the effect for those with non-member neighbors. Specification (10) presents the results for those near the border and there is no crowding-in effect identified. But in specification (11), where the treated sample includes only wells that have neighbor wells that are also treated, the effect is twice as large in magnitude and statistically significant. This distinct difference lends credence that the effect is not purely financial and that

[24] Though this lagged model may be preferable from a theoretical standpoint, the lagged variable reduces the panel length and subsequently relies on only one year – 2010 – to establish a pre-intervention baseline making the econometric framework more tenuous.

[25] Weighting nearby pumping by $\frac{abs(H_{it}-H_{jt})}{d_{ij}}$, where $abs(H_{it}-H_{jt})$ is the absolute value of the difference in groundwater height beneath well i and j in year t, and d_{ij} is the distance between them.Ā true weighting by the net flow rate of Darcy's Law requires multiplying that term by the hydroconductivity or transmissivity of the ground material at well j (Sears et al., 2017). Unfortunately, in contrast to the Ogallala Aquifer, the SLV aquifer does not have any spatially explicit data to draw upon. In addition to my own efforts to locate such data, I reached out to two Hydrologists living in Colorado that study such issues who were also unaware of any such data existing.

[26] The results do, at first blush, suggest that subdistrict #2 did reduce pumping significantly on average (−113.6 AF), but this is countered by the estimated impact of the placebo fee (2.763 AF/Dollar × 65 Dollar = 179.6 AF). Therefore these "effects" are just spurious results offsetting one another.

[27] This definition creates different groups for different radii. By the 3-mile radius, very few wells have nearby pumping only within the same ditch.

[28] In practice, due to the relatively well-defined geographic area, these are primarily those along the southern border near the Rio Grande.

some social norms are crowded in. However, the distinction does not help narrow the channel through which the additional conservation emerges. Those near the border may not be reducing their competitive pumping because their neighbors 1) do not face the tax and therefore the incentive to "retaliate" remains, 2) did not signal their commitment to conservation by voting for the tax, or 3) were not part of the collaborative process that fostered additional trust.

Last, an hypothesis for why the crowding-in effect appearing is that irrigators have a reciprocal role, both creator and recipient of the externality. Because all irrigators fit this classification, I cannot definitely test for this mechanism, but I can provide some evidence that those exposed to a more severe externality pre-treatment are likely to respond more post-treatment. To do so, I classify subdistrict wells by how far their water levels fell in the pre-treatment period using the maximum single year loss. Those that lost more than the median amount are considered to face a "high externality". The results for the low- and high-externality wells are given in specification (12) and (13) respectively. Consistent with the hypothesis, the low-externality wells do not exhibit as large as a crowding effect in magnitude or statistical significance.

7. Conclusion

On net, I find that the fee did reduce pumping considerably and that some of the reduction is attributable to a shift in social norms towards conservation. This is important in the general sense: economic prices can crowd-in social norms rather than crowding them out. It is likely that the dual role and symmetry between the irrigators played a role. Because of this, adopting the pumping fee provided a credible commitment device to move towards a better social outcome, resulting in reductions beyond what the actual pecuniary incentives would directly have led to.[29] Tradable permits would likely not have the same crowding-in effect. In the context of pollution-market based regulations, outcomes for permits and taxes are distinct even when marginal costs are known (but marginal damages are not) by the regulator due to distinct behavioral responses (Heres and Lin Lawell, 2017).[30] In the groundwater context, even though the permit price provides a signal, an irrigator that conserves more will likely sell the permit, meaning someone will extract the groundwater.

Two important and related questions remain. First, when can the introduction of prices be expected to crowd-out social norms or crowd them in? The answer remains beyond the scope of this paper, though considering the scenario can help develop hypotheses: 1) the internal process, 2) prior monetary relationship with the resource, 3) symmetric roles, and 4) prior collective-action on surface-ditches are all plausible explanations. The second question that remains is how effective a groundwater fee is in changing pumping behavior. In other words, was it the internal process, the use of a price, or the combination? Though the SLV fee produced a substantial reduction, it is not clear that policy makers should impose fees elsewhere expecting a similar response. Not only do the physical realities of aquifers differ across sites, but irrigators also vary. In addition, an externally imposed tax may be less likely to bring about a crowding-in effect. If an external tax crowds-out any existing conservation behavior, it would be even more problematic.

Meanwhile, a local collaborative process that does not result in financial incentives may be less likely to increase conservation. Without a commitment to prices, the communications and agreements could be viewed as cheap talk that do not provide users a collective confidence of cooperative behavior in future periods, eroding conservation now. Evidence from experiments suggests that facilitating communication is more effective than conditional payments, but the conservation is the greatest in cases where both communication and conditional payments were introduced (Andersson et al., 2018). This is consistent with the contention that the internal source of the price contributes to the crowding effect, while the implementation of the fee bolsters the social norms fostered through the collaborative process. Policymakers should consider the crowding results that are made possible if aquifer users are encouraged to adopt their own rules, where the process can shift behavior independent of, and likely interacted with, the final set of rules settled upon.

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[29] It should be noted that no dynamic welfare analysis is conducted. Accordingly, I cannot definitively show that the reduction in pumping, given the fee, is a better equilibrium.

[30] They find that under a tax more production will occur due to overweighting high damage events and risk seeking to avoid losses, behavior present in both contexts but production is firmly capped under the permit system.

Appendix A

Table A1
Spatial correlation.

VARIABLES	Moran's I	E(I)	sd(I)	z	p-value*
Change in Pumping	0.128	0	0.045	2.841	0.002
Permitted Flow	0.347	0	0.046	7.611	0

Note: Moran's I statistic calculated for 3060 wells in data sample. Spatial matrix is the inverse distance (miles) cutoff at 3 miles.

Table A2
Change in groundwater height (interacted).

VARIABLES	(1)	(2)	(3)	(4)
	GW Depth	GW Depth	GW Depth	GW Depth
Own Pumping	−0.00442***	−0.00428***	−0.00425***	−0.00423***
	(0.000904)	(0.000909)	(0.000912)	(0.000910)
Own Pumping × Subdistrict	0.00178	0.00197	0.00196	0.00187
	(0.00124)	(0.00123)	(0.00123)	(0.00123)
Neighbor Pumping	−0.000493***	−0.000263***	−0.000153***	−0.000128***
	(0.000119)	(4.15e-05)	(2.36e-05)	(1.80e-05)
Neighbor Pumping × Subdistrict	−5.43e-05	8.55e-05*	5.27e-05**	5.78e-05***
	(0.000130)	(4.41e-05)	(2.47e-05)	(1.87e-05)
Own Nearby Pumping	−0.00188**	−0.000824	−0.000407	−0.000237
	(0.000905)	(0.000531)	(0.000303)	(0.000207)
Own Nearby Pumping × Subdistrict	0.00177	0.00169**	0.00145***	0.00118***
	(0.00112)	(0.000723)	(0.000494)	(0.000441)
Subdistrict	−0.592**	−0.817***	−0.778***	−0.869***
	(0.239)	(0.259)	(0.256)	(0.270)
Constant	7.234***	7.584***	7.632***	7.744***
	(0.430)	(0.457)	(0.454)	(0.466)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	14,674	14,674	14,674	14,674
R-squared	0.095	0.095	0.096	0.096

Note: Dependent variable is change in groundwater height from year t-1 to t at well i in year t. Well pumping is AF pumped at well i in year t. Neighbor pumping and own pumping are cumulative pumping within the specified range. Surface water inflow and year fixed effects are suppressed. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A3
Overall well level change.

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet (log)	Acre Feet
Subdistrict	−28.87***	−30.42***	−0.0425	−28.87***
	(10.54)	(10.51)	(0.112)	(10.54)
Subdistrict × Post	−63.54***			−20.37**
	(5.212)			(10.10)
Fee		−0.930***		−0.659***
		(0.0748)		(0.147)
ln (Fee+40)			−0.706***	
			(0.0572)	
Surface Water	−0.0210**	−0.0209**	−5.95e-05	−0.0208**
	(0.00898)	(0.00894)	(9.39e-05)	(0.00894)
Surface Water × Decree	−0.0611***	−0.0612***	−0.000703***	−0.0629***
	(0.0228)	(0.0226)	(0.000213)	(0.0228)
Surface Water × Decree × Post	−0.0507**	−0.0625***	−8.27e-05	−0.0561***
	(0.0200)	(0.0195)	(0.000190)	(0.0203)
Parcels Served	28.36***	28.44***	0.285***	28.44***
	(2.493)	(2.492)	(0.0219)	(2.493)
Sprinkler Indicator	75.23***	75.02***	2.156***	74.98***
	(6.594)	(6.593)	(0.0932)	(6.595)
Latitude	−0.00168***	−0.00168***	−1.47e-05***	−0.00168***
	(0.000333)	(0.000333)	(3.93e-06)	(0.000333)
Longitude	0.000175	0.000178	3.70e-06**	0.000177
	(0.000190)	(0.000190)	(1.77e-06)	(0.000190)

(*continued on next page*)

Table A3 (*continued*)

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet (log)	Acre Feet
Well Depth	0.138***	0.138***	0.00123***	0.138***
	(0.0117)	(0.0117)	(9.16e-05)	(0.0117)
Decreed Flow	4.082***	4.080***	−0.0150	4.079***
	(1.333)	(1.333)	(0.0128)	(1.333)
Constant	−25.36	−38.23	−4.883	−37.01
	(818.3)	(818.4)	(8.079)	(818.5)
Observations	15,239	15,239	15,239	15,239
R-squared	0.397	0.397	0.332	0.397

Note: Difference in Difference estimates using acre feet pumped as the dependent variable. Additional controls include year fixed effects and surface ditch fixed effects. Robust standard errors, clustered by well, in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A4
Spatial correlation of changes.

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet (Average Change)	Acre Feet (Average Change)	Acre Feet (Average Change)	Acre Feet (Average Change)
Neighbor Pumping (Average Change)	0.0219***	0.00809***	0.00397***	0.00322***
	(0.00530)	(0.00211)	(0.00136)	(0.00108)
Constant	1602**	1346**	1449**	1473**
	(621.8)	(638.8)	(654.6)	(650.6)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	2123	2123	2123	2123
R-squared	0.020	0.019	0.016	0.017

Note: Cross-Sectional regressions with average pumping post treatment minus average pumping pre-treatment as the dependent variable. Neighbor Pumping is defined similarly but by summing pumping by all wells within the range before averaging across time. Additional but unreported controls are well depth, decreed flow, and latitude and longitude. Only subdistrict #1 wells are included. Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A5
Spatial relationship (OLS).

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping	0.00850***	0.00270***	0.00131***	0.000839***
	(0.00242)	(0.000658)	(0.000327)	(0.000221)
Own Nearby Pumping	−0.0789**	−0.000548	0.00784	0.00183
	(0.0318)	(0.0240)	(0.0171)	(0.0122)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	15,239	15,239	15,239	15,239
R-squared	0.391	0.390	0.389	0.389

Note: Dependent variable is pumping at well i in year t. Neighbor pumping is cumulative pumping within the specified range. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A6
Equal trends (IV).

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping	−0.0152	−0.00155	−0.000791	0.000189
	(0.0115)	(0.00342)	(0.00193)	(0.00156)
Neighbor Pumping × Subdistrict	0.0157	0.00107	0.000386	−0.000521
	(0.0118)	(0.00343)	(0.00195)	(0.00157)
Neighbor Pumping × 2010	−0.0109	0.00101	0.00114	0.00147
	(0.00950)	(0.00290)	(0.00163)	(0.00129)
Neighbor Pumping × Subdistrict × 2010	0.0159	−0.000294	−0.00102	−0.00145
	(0.00989)	(0.00294)	(0.00166)	(0.00131)
Own Nearby Pumping	−0.272***	−0.149***	−0.108***	−0.0932***
	(0.0374)	(0.0320)	(0.0266)	(0.0254)

Table A6 (*continued*)

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Constant	−525.0	−202.9	−236.3	−140.4
	(885.3)	(895.7)	(890.2)	(888.0)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	6098	6098	6098	6098
R-squared	0.340	0.331	0.329	0.330
Minimum Adj. Partial Shea's R-Squared	0.364	0.563	0.670	0.674

Note: Dependent variable is pumping at well i in year t. Neighbor pumping is cumulative pumping within the specified range instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the two endogenous nearby pumping variables. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A7
Impact of economic intervention with spatial controls (OLS).

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post × Subdistrict	−0.00678	0.000142	−0.000349	8.21e-05
	(0.00623)	(0.00176)	(0.000925)	(0.000725)
Neighbor Pumping	0.00230	0.00541**	0.00335***	0.00320***
	(0.00737)	(0.00231)	(0.00124)	(0.000991)
Neighbor Pumping × Subdistrict	0.00614	−0.00371	−0.00283**	−0.00293***
	(0.00771)	(0.00234)	(0.00126)	(0.00100)
Neighbor Pumping × Post	0.00436	−0.000716	0.000251	−0.000149
	(0.00607)	(0.00173)	(0.000909)	(0.000717)
Own Nearby Pumping	−0.0838***	−0.00140	0.00878	0.00228
	(0.0311)	(0.0239)	(0.0170)	(0.0121)
Post × Subdistrict	−15.22	−16.82	−13.25	−13.15
	(11.18)	(11.31)	(11.54)	(11.82)
Fee	−0.650***	−0.637***	−0.661***	−0.689***
	(0.149)	(0.149)	(0.150)	(0.150)
Constant	−155.5	150.0	189.5	133.2
	(804.1)	(801.1)	(798.2)	(802.3)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	15,239	15,239	15,239	15,239
R-squared	0.401	0.399	0.400	0.400

Note: Dependent variable is pumping at well i in year t. Neighbor pumping is cumulative pumping within the specified range. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A8
Main results, spatial and temporal correlated error correction.

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post × Subdistrict	−0.0178*	−0.00387	−0.00368**	−0.00264**
	(0.00993)	(0.00264)	(0.00146)	(0.00113)
Neighbor Pumping	−0.0154*	−0.00211	−0.00140	−0.000426
	(0.00791)	(0.00219)	(0.00123)	(0.000978)
Neighbor Pumping × Subdistrict	0.0183**	0.00234	0.00139	0.000349
	(0.00815)	(0.00224)	(0.00125)	(0.000991)
Neighbor Pumping × Post	0.0156	0.00306	0.00335**	0.00244**
	(0.00956)	(0.00257)	(0.00143)	(0.00111)
Own Nearby Pumping	−0.244***	−0.125***	−0.0978***	−0.0843***
	(0.0166)	(0.0125)	(0.00976)	(0.00759)
Post × Subdistrict	−3.863	−6.684	3.958	6.510
	(18.08)	(18.42)	(18.57)	(18.78)
Fee	−0.804***	−0.737***	−0.750***	−0.775***
	(0.239)	(0.240)	(0.239)	(0.239)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	15,239	15,239	15,239	15,239

Note: Dependent variable is pumping at well i in year t. Neighbor pumping is cumulative pumping within the specified range instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, allowing for spatial and temporal autocorrelation, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A9
Impact of economic intervention with spatial controls (IV-Single Difference).

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post	−0.00184	−0.000828*	−0.000376*	−0.000233
	(0.00180)	(0.000431)	(0.000214)	(0.000144)
Neighbor Pumping	0.000560	−0.000506	−0.000380	−0.000300
	(0.00307)	(0.000793)	(0.000432)	(0.000290)
Own Nearby Pumping	−0.309***	−0.215***	−0.197***	−0.170***
	(0.0302)	(0.0298)	(0.0322)	(0.0350)
Fee	−1.257***	−1.211***	−1.211***	−1.212***
	(0.0636)	(0.0643)	(0.0656)	(0.0657)
Constant	−5651***	−6416***	−6763***	−6438***
	(957.1)	(993.0)	(1063)	(1078)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	10,739	10,739	10,739	10,739
R-squared	0.322	0.308	0.297	0.302
Minimum Adj. Partial Shea's R-Squared	0.580	0.739	0.784	0.812

Note: Dependent variable is pumping at well i in year t. Only subdistrict #1 wells are included. Neighbor pumping is cumulative pumping within the specified range instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the two endogenous nearby pumping variables. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A10
Impact of economic intervention with spatial controls and groundwater height.

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post × Subdistrict	−0.0196**	−0.00443*	−0.00400***	−0.00296***
	(0.00993)	(0.00250)	(0.00135)	(0.00104)
Neighbor Pumping	−0.0175*	−0.00297	−0.00189	−0.000860
	(0.0106)	(0.00312)	(0.00175)	(0.00142)
Neighbor Pumping × Subdistrict	0.0210*	0.00328	0.00199	0.000908
	(0.0109)	(0.00317)	(0.00179)	(0.00144)
Neighbor Pumping × Post	0.0171*	0.00354	0.00361***	0.00269***
	(0.00979)	(0.00247)	(0.00133)	(0.00103)
Own Nearby Pumping	−0.242***	−0.121***	−0.0950***	−0.0820***
	(0.0317)	(0.0264)	(0.0221)	(0.0207)
Post × Subdistrict	−7.125	−9.787	1.420	4.574
	(12.71)	(13.04)	(13.17)	(13.53)
Fee	−0.769***	−0.701***	−0.711***	−0.732***
	(0.160)	(0.159)	(0.159)	(0.159)
GW Height	0.111	0.118	0.119	0.130*
	(0.0735)	(0.0760)	(0.0775)	(0.0786)
Constant	−1579	−1341	−1450	−1536
	(1254)	(1286)	(1296)	(1304)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	14,794	14,794	14,794	14,794
R-squared	0.397	0.389	0.389	0.390
Minimum Adj. Partial Shea's R-Squared	0.422	0.601	0.701	0.703

Note: Dependent variable is pumping at well i in year t. Neighbor pumping is cumulative pumping within the specified range instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A11
Impact of economic intervention on the extensive margin.

VARIABLES	(1)	(2)	(3)	(4)
	Acres	Acres	Acres	Acres
Neighbor Pumping × Post × Subdistrict	−0.00811***	−0.00205***	−0.000994**	−0.000457
	(0.00301)	(0.000796)	(0.000470)	(0.000368)
Neighbor Pumping	−0.00789	−0.00187	−0.000728	−0.000112
	(0.00504)	(0.00143)	(0.000803)	(0.000641)
Neighbor Pumping × Subdistrict	0.0128**	0.00286**	0.00108	0.000276
	(0.00510)	(0.00144)	(0.000818)	(0.000644)
Neighbor Pumping × Post	0.00713**	0.00179**	0.000884*	0.000382
	(0.00299)	(0.000786)	(0.000468)	(0.000371)
Own Nearby Pumping	−0.225***	−0.144***	−0.111***	−0.0885***
	(0.0177)	(0.0156)	(0.0156)	(0.0179)
Post × Subdistrict	20.39***	16.11***	17.61***	17.36***
	(3.871)	(4.552)	(4.182)	(3.865)
Fee	−0.224***	−0.143***	−0.145***	−0.162***
	(0.0368)	(0.0373)	(0.0358)	(0.0357)
Constant	−647.3**	−485.9	−568.6*	−456.5
	(323.2)	(341.3)	(341.0)	(337.3)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	15,239	15,239	15,239	15,239
R-squared	0.566	0.557	0.556	0.555
Minimum Adj. Partial Shea's R-Squared	0.416	0.598	0.699	0.702

Note: Dependent variable is irrigated acreage served by well i in year t. Neighbor pumping is cumulative pumping within the specified range instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A12
Impact of economic intervention on the intensive margin.

VARIABLES	(1)	(2)	(3)	(4)
	AF/Acre	AF/Acre	AF/Acre	AF/Acre
Neighbor Pumping × Post × Subdistrict	1.33e-05	6.40e-05	−1.90e-05	−3.66e-05
	(0.000267)	(7.40e-05)	(3.92e-05)	(3.05e-05)
Neighbor Pumping	0.000437	0.000110	4.04e-05	2.86e-05
	(0.000272)	(7.43e-05)	(3.99e-05)	(3.22e-05)
Neighbor Pumping × Subdistrict	−0.000286	−9.16e-05	−3.80e-05	−2.81e-05
	(0.000272)	(7.37e-05)	(4.02e-05)	(3.27e-05)
Neighbor Pumping × Post	−5.26e-05	−7.54e-05	1.43e-05	3.39e-05
	(0.000263)	(7.31e-05)	(3.88e-05)	(3.03e-05)
Own Nearby Pumping	−0.00525***	−0.00297***	−0.00192**	−0.00169***
	(0.000549)	(0.000951)	(0.000803)	(0.000649)
Post × Subdistrict	−0.510	−0.766**	−0.427	−0.213
	(0.360)	(0.389)	(0.399)	(0.438)
Fee	−0.0155***	−0.0139**	−0.0146**	−0.0153**
	(0.00603)	(0.00604)	(0.00614)	(0.00623)
Constant	−21.97	−18.53	−18.10	−17.24
	(16.61)	(16.68)	(16.32)	(16.29)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	15,239	15,239	15,239	15,239
R-squared	0.370	0.365	0.361	0.361
Minimum Adj. Partial Shea's R-Squared	0.416	0.598	0.699	0.702

Note: Dependent variable is pumping per acre by well i in year t. Neighbor pumping is cumulative pumping within the specified range instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A13
Impact of economic intervention with lagged spatial controls (IV).

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post × Subdistrict	−0.0561***	−0.00926**	−0.00676***	−0.00410*
	(0.0200)	(0.00465)	(0.00262)	(0.00210)
Neighbor Pumping	−0.0351*	−0.00348	−0.00270	−0.000938
	(0.0201)	(0.00518)	(0.00292)	(0.00239)
Neighbor Pumping × Subdistrict	0.0506**	0.00709	0.00425	0.00184
	(0.0202)	(0.00516)	(0.00293)	(0.00239)
Neighbor Pumping × Post	0.0381*	0.00429	0.00454*	0.00272
	(0.0199)	(0.00464)	(0.00261)	(0.00211)
Own Nearby Pumping	−0.232***	−0.115***	−0.0929***	−0.0804***
	(0.0338)	(0.0279)	(0.0226)	(0.0207)
Post × Subdistrict	37.28**	27.05*	32.08**	26.96
	(15.26)	(14.98)	(15.81)	(16.75)
Fee	−0.817***	−0.712***	−0.656***	−0.637***
	(0.157)	(0.159)	(0.157)	(0.158)
Constant	−874.6	−565.2	−647.8	−598.1
	(826.5)	(849.5)	(848.1)	(845.4)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	12,178	12,178	12,178	12,178
R-squared	0.413	0.407	0.405	0.407
Minimum Adj. Partial Shea's R-Squared	0.126	0.183	0.205	0.200

Note: Dependent variable is pumping at well i in year t. Neighbor pumping is lagged one year and is the cumulative pumping within the specified range instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A14
Impact of economic intervention with spatial controls (IV and Weights).

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post × Subdistrict	−0.000574	−0.000579*	−0.000590*	−0.000596*
	(0.000352)	(0.000347)	(0.000346)	(0.000345)
Neighbor Pumping	−7.59e-05	−7.92e-05	−8.10e-05	−8.19e-05
	(0.000182)	(0.000179)	(0.000178)	(0.000178)
Neighbor Pumping × Subdistrict	7.39e-05	7.68e-05	7.85e-05	7.94e-05
	(0.000184)	(0.000181)	(0.000180)	(0.000179)
Neighbor Pumping × Post	0.000570	0.000576*	0.000587*	0.000593*
	(0.000352)	(0.000346)	(0.000346)	(0.000345)
Own Nearby Pumping	0.000844	0.000983	0.000978	0.000938
	(0.00310)	(0.00308)	(0.00308)	(0.00309)
Post × Subdistrict	−16.01	−15.60	−15.32	−15.14
	(10.19)	(10.21)	(10.23)	(10.25)
Fee	−0.671***	−0.672***	−0.672***	−0.673***
	(0.146)	(0.146)	(0.146)	(0.146)
Constant	−40.58	−43.08	−43.93	−44.55
	(818.3)	(818.5)	(818.5)	(818.6)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	15,239	15,239	15,239	15,239
R-squared	0.397	0.397	0.397	0.397
Minimum Adj. Partial Shea's R-Squared	0.543	0.536	0.549	0.538

Note: Dependent variable is pumping at well i in year t. Only subdistrict #1 wells are included. Neighbor pumping is cumulative pumping within the specified range instrumented by permitted flow being weighted by distance and difference in groundwater height prior to the summation. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A15
Subdistrict 2 placebo with spatial controls (IV).

VARIABLES	(1)	(2)	(3)	(4)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post × Subdistrict 2	−0.0203	−0.00847	0.000973	0.00316
	(0.0717)	(0.0253)	(0.0181)	(0.0179)
Neighbor Pumping	−0.0102	−0.000834	−0.000341	0.000462
	(0.0102)	(0.00293)	(0.00162)	(0.00130)
Neighbor Pumping × Subdistrict 2	0.0265	0.0149	0.00597	0.000400
	(0.0711)	(0.0286)	(0.0222)	(0.0243)
Neighbor Pumping × Post	0.0116	0.00223	0.00252**	0.00195**
	(0.00848)	(0.00213)	(0.00116)	(0.000898)
Own Nearby Pumping	−0.208***	−0.0726	−0.0548*	−0.0513**
	(0.0738)	(0.0471)	(0.0317)	(0.0259)
Post × Subdistrict 2	−121.0**	−113.6*	−123.2	−132.0
	(49.56)	(58.17)	(75.32)	(94.01)
Fee	2.941***	2.763***	2.465***	2.528***
	(0.694)	(0.748)	(0.831)	(0.968)
Constant	−1956*	−1732	−1825*	−1970*
	(1115)	(1108)	(1097)	(1101)
Range	0.25 Miles	1 Mile	2 Miles	3 Miles
Observations	4500	4500	4500	4500
R-squared	0.376	0.382	0.384	0.386
Minimum Adj. Partial Shea's R-Squared	0.357	0.400	0.304	0.223

Note: Dependent variable is pumping at well i in year t. Sample includes non-Subdistrict 1 wells only and prescribes treatment to subdistrict #2 well. Neighbor pumping is cumulative pumping within the specified range instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A16
Impact of economic intervention with spatial controls (IV) by neighbor's ditch membership.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post × Subdistrict	−0.0166*	−0.0214**	−0.00376	−0.00778*	−0.00367***	−0.863	Insufficient Identification	
	(0.00967)	(0.0105)	(0.00236)	(0.00460)	(0.00127)	(4.765)		
Neighbor Pumping	−0.0149	−0.0124	−0.00207	−0.00103	−0.00140	−0.000733		
	(0.0105)	(0.0104)	(0.00306)	(0.00304)	(0.00170)	(0.00171)		
Neighbor Pumping × Subdistrict	0.0199*	−0.00117	0.00234	−0.0213	0.00140	−0.257*		
	(0.0108)	(0.0128)	(0.00308)	(0.0211)	(0.00173)	(0.153)		
Neighbor Pumping × Post	0.0153	0.0147	0.00305	0.00269	0.00335***	0.00313**		
	(0.00950)	(0.00937)	(0.00233)	(0.00232)	(0.00126)	(0.00125)		
Own Nearby Pumping	−0.250***	−0.201***	−0.120***	−0.0844*	−0.0959***	−0.0549*		
	(0.0381)	(0.0525)	(0.0281)	(0.0466)	(0.0229)	(0.0330)		
Post × Subdistrict	−7.016	36.63**	−8.377	174.7**	2.750	18,975		
	(12.47)	(16.63)	(12.32)	(73.58)	(12.41)	(94,227)		
Fee	−0.781***	−0.984***	−0.714***	−2.120**	−0.735***	−116.0		
	(0.157)	(0.189)	(0.153)	(0.957)	(0.153)	(487.1)		
Constant	−916.6	−1188	−516.7	−1152	−543.1	−1386		
	(834.8)	(956.2)	(835.6)	(1011)	(829.5)	(1126)		
Subdistrict Sample	Different Ditch	Same Ditch	Different Ditch	Same Ditch	Different Ditch	Same Ditch	Different Ditch	Same Ditch
Range	0.25 Miles		1 Mile		2 Miles		3 Miles	
Observations	12,613	7126	14,674	5065	15,124	4615		
R-squared	0.386	0.401	0.383	0.373	0.382	0.145		
Minimum Adj. Partial Shea's R-Squared	0.414	0.408	0.598	0.208	0.699	−0.033		

Note: Dependent variable is pumping at well i in year t. Neighbor pumping is cumulative pumping within the specified range instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Subdistrict sample is divided by whether neighbor pumping includes wells from a different surface organization. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A17
Impact of economic intervention with spatial controls (IV) by neighbor's treatment.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post × Subdistrict	−0.0153	−0.0210**	−0.00288	−0.00427*	−0.00332**	−0.00351***	−0.00256***	−0.00199**
	(0.0110)	(0.00988)	(0.00248)	(0.00245)	(0.00129)	(0.00131)	(0.000988)	(0.00100)
Neighbor Pumping	−0.0141	−0.0143	−0.00183	−0.00173	−0.00121	−0.00117	−0.000257	−5.28e-05
	(0.0105)	(0.0105)	(0.00303)	(0.00307)	(0.00168)	(0.00170)	(0.00135)	(0.00136)
Neighbor Pumping × Subdistrict	0.0409***	0.00463	0.00691**	−0.000113	0.00313*	−1.81e-05	0.00152	−0.000464
	(0.0140)	(0.0113)	(0.00338)	(0.00334)	(0.00177)	(0.00187)	(0.00139)	(0.00146)
Neighbor Pumping × Post	0.0148	0.0155	0.00299	0.00303	0.00329***	0.00334***	0.00239**	0.00236**
	(0.00941)	(0.00950)	(0.00232)	(0.00234)	(0.00125)	(0.00125)	(0.000968)	(0.000969)
Own Nearby Pumping	−0.203***	−0.254***	−0.0847**	−0.126***	−0.0730***	−0.0870***	−0.0692***	−0.0707***
	(0.0622)	(0.0349)	(0.0368)	(0.0326)	(0.0262)	(0.0258)	(0.0220)	(0.0242)
Post × Subdistrict	−22.54	21.45	−25.48*	17.28	−10.25	25.14	−2.689	13.26
	(14.45)	(13.61)	(14.10)	(15.26)	(13.59)	(15.79)	(13.60)	(16.72)
Fee	−0.423**	−1.138***	−0.377**	−1.048***	−0.485***	−1.037***	−0.579***	−0.904***
	(0.177)	(0.168)	(0.173)	(0.187)	(0.165)	(0.196)	(0.161)	(0.205)
Constant	−961.0	−651.0	−766.8	−323.3	−827.4	−184.5	−713.2	−581.5
	(948.9)	(853.6)	(917.5)	(906.7)	(895.9)	(932.3)	(867.5)	(955.4)
Subdistrict Sample	Border	Inside	Border	Inside	Border	Inside	Border	Inside
Range	0.25 Miles		1 Mile		2 Miles		3 Miles	
Observations	6576	13,163	7536	12,203	8530	11,209	9695	10,044
R-squared	0.375	0.396	0.377	0.395	0.371	0.407	0.370	0.421
Minimum Adj. Partial Shea's R-Squared	0.407	0.414	0.595	0.579	0.698	0.661	0.701	0.684

Note: Dependent variable is pumping at well i in year t. Neighbor pumping is cumulative pumping within the specified range instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Subdistrict sample is divided by whether neighbor pumping includes non-subdistrict wells. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table A18
Impact of economic intervention with spatial controls (IV) by externality exposure.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet	Acre Feet
Neighbor Pumping × Post × Subdistrict	−0.0154	−0.0203**	−0.00349	−0.00450*	−0.00346***	−0.00396***	−0.00253**	−0.00275***
	(0.00985)	(0.00971)	(0.00243)	(0.00239)	(0.00130)	(0.00128)	(0.000990)	(0.000988)
Neighbor Pumping	−0.0133	−0.0143	−0.00167	−0.00165	−0.00114	−0.00110	−0.000198	−0.000167
	(0.0104)	(0.0105)	(0.00304)	(0.00305)	(0.00168)	(0.00169)	(0.00135)	(0.00135)
Neighbor Pumping × Subdistrict	0.0197*	0.0132	0.00220	0.00128	0.00123	0.000758	0.000254	−0.000177
	(0.0111)	(0.0111)	(0.00315)	(0.00317)	(0.00176)	(0.00176)	(0.00139)	(0.00139)
Neighbor Pumping × Post	0.0150	0.0152	0.00300	0.00295	0.00330***	0.00328***	0.00239**	0.00237**
	(0.00945)	(0.00944)	(0.00233)	(0.00233)	(0.00125)	(0.00125)	(0.000966)	(0.000968)
Own Nearby Pumping	−0.238***	−0.223***	−0.113***	−0.102***	−0.0857***	−0.0754***	−0.0719***	−0.0686***
	(0.0479)	(0.0402)	(0.0393)	(0.0313)	(0.0290)	(0.0239)	(0.0242)	(0.0223)
Post × Subdistrict	−12.80	15.50	−11.43	12.27	−0.808	23.13	−819.9	−498.7
	(13.14)	(14.04)	(13.46)	(14.55)	(13.55)	(14.52)	(862.8)	(914.6)
Fee	−0.647***	−0.978***	−0.632***	−0.889***	−0.642***	−0.908***	−0.579***	−0.904***
	(0.164)	(0.167)	(0.163)	(0.166)	(0.163)	(0.166)	(0.161)	(0.205)
Constant	−1111	−740.1	−786.1	−458.5	−847.2	−497.6	−713.2	−581.5
	(855.1)	(910.4)	(870.9)	(920.0)	(865.6)	(916.5)	(867.5)	(955.4)
Subdistrict Sample	Low Externality	High Externality	Low Externality	High Externality	Low Externality	High Externality	Low Externality	High Externality
Range	0.25 Miles		1 Mile		2 Miles		3 Miles	
Observations	10,000	9739	10,000	9739	10,000	9739	10,000	9739
R-squared	0.406	0.381	0.403	0.379	0.404	0.380	0.407	0.381
Minimum Adj. Partial Shea's R-Squared	0.412	0.412	0.596	0.596	0.698	0.698	0.702	0.701

Note: Dependent variable is pumping at well i in year t. Neighbor pumping is cumulative pumping within the specified range instrumented by permitted flow. Partial Shea's R-Squared reports the smallest R-squared of the four endogenous nearby pumping variables. Subdistrict sample is divided by the median groundwater level drop prior to treatment. Additional controls include surface water supply, # of parcels served, technology used, well depth, decreed flow, latitude and longitude, and surface ditch fixed effects. Robust standard errors, clustered by well, are in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

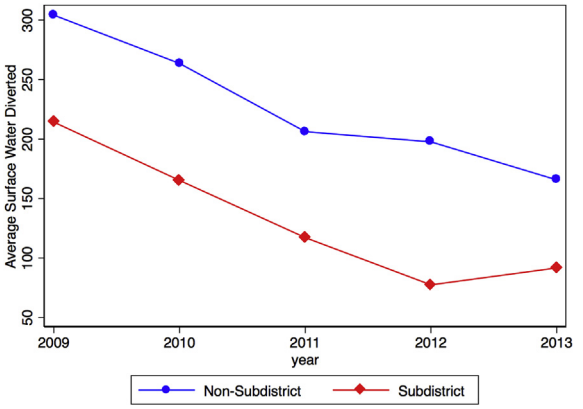

Fig. A1. Average surface water diversion per well by year measured in acre-feet.

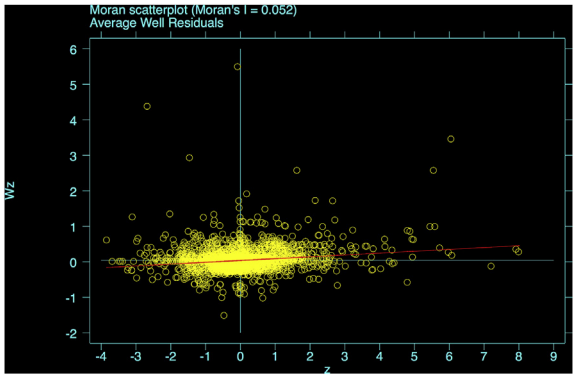

Fig. A2. Spatial Correlation of residuals from the 1-mile radius regression. Spatial weight matrix includes neighbors within 3 miles. Graph created by spatlsa in Stata.

Appendix B: Permitted flow

While permitted flows are generally spatially correlated, their remains sufficient qualitative and quantitative evidence to suggest permitted flow for neighbors is independent of permitted flow (and subsequently pumping) of a given well; i.e. $cov\left(\sum_{j\in(0,ub)} permit_j, \epsilon_{it}\right) = 0$. First, as shown in the main text, there is no statistical relationship between the nearby permits and the permit for well i conditional on the other covariates.

Some of this random variation can be attributed to variation in the pumping tests that accompany the permitting process, ultimately playing a critical role in the permitted flow determination. The Office of the State Engineer would run pump for a number of hours to determine the sustained maximum yield. Most often this occurred at the time of the construction with a test pump (the median and mode of the difference between first year of pumping and year of permit is zero for wells that have data available: N = 1,221). At times the test would occur 1 to 2 years prior to use, and as much as 16 in the most extreme case. But other "tests" occurred after the first beneficial use. In fact, 44 percent of the sample had permits issued after the first use. In these instances it is most likely that the test was conducted with the already installed pump.

Furthermore, tests were not always conducted of equal length. Though recorded on the original permits, this information is not included in the downloadable data sets of water rights and well information. But I have downloaded a number of the original permits in a random fashion (selecting wells "randomly" on a map, though I am sure like most humans, I failed at truly randomizing this selection). Regardless, within those selected, I found tests that ran for 4, 5, 6, 8, and 12 hours. The length of the test can lead to different results (longer tests are likely to be more accurate). This variation in testing technique could result in variable yield measurements, even in the same vicinity of other wells that would in fact have similar yields.

Importantly, the wells (and permits) are generally much earlier than the drought years of the 21st century and the policy intervention being studied. Shown in Fig. B1 below, many were developed in the 40s and 50s, though the largest flurry of activity took place around 1980, just before new wells were generally disallowed (some replacement wells are permitted).

Also shown in Fig. B1 is an additional source of variation in the permitted flow that appears to be random. Generally speaking the yield from the tests were translated from gallons per minute to cubic feet per second. Given this conversion the yield, when divided by permitted flow, should equal 448.83. And indeed this is the most common number: 75.12 percent of the ratios fall between 447 and 450. However, there is considerable variation beyond this, shown in Fig. B1 plotted against the

year of first use. Based on casual ocular analysis, there does not appear to be a relationship between the time of well development and variation in this ratio. Though efforts have been made, there is no clear answer why this ratio is not in fact always the same save for rounding errors.

Therefore, even beyond the variation in yield tests, the translation to permitted flow appears to introduce yet another random dimension. Furthermore, the ratio not only exhibits no systematic relationship to the year of first use, but I was unable to find any systematic relationship to other variables of interest. Table B1 provides regression results with this ratio as the dependent variable with a number of variables of interest, both in a multivariable context and single variable regressions. First, there is no evidence that those in the subdistrict are more or less likely to have a higher ratio. Second, pumping at the well has no statistical relationship to the ratio. This is important because it suggests pumping is sensitive to the permitted flow and not the yield. For instance, if irrigators simply ignored the permitted flow and pumped according to the maximum yield (as measured by the test), than we would expect those with a higher ratio (more yield to permit) to actually pump more. Third, and equally important, the ratio does not exhibit a statistical relationship to nearby cumulative permits, giving credence to the claim that this variation in permitted flow is independent of nearby permits. Additionally, X- and Y-coordinate variables do not have a statistical relationship with the ratio, further supporting that the variation in the ratio is not inherently spatially related.

On net, the permitted flow of nearby pumping appears to meet the requirements of a valid instrument: 1) it strongly predicts nearby pumping, 2) permitted flow at neighboring well should not impact pumping at a given well other than through the indirect effect transmitted through pumping at the neighboring well, and 3) that conditional covariates, the neighboring permits appear as a good as random.

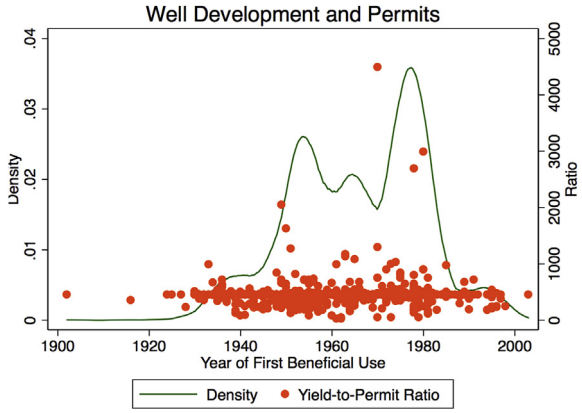

Fig. B1. Plots the frequency of well development (year of first use) along with the ratio of yield-to-permitted flow.

Table B1
OLS regressions for yield-to-permitted flow ratio.

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio
Subdistrict	−0.591	0.161							
	(9.094)	(6.276)							
Pumping	−0.0127		−0.0144						
	(0.0294)		(0.0240)						
Neighbor Permit (1 mile)	0.0200			0.0162					
	(0.0315)			(0.0266)					
First year of beneficial use	0.237				0.300				
	(0.254)				(0.237)				
Well Depth	0.00286					−0.00442			
	(0.0120)					(0.00859)			
X-Coordinate	0.000244						0.000135		
	(0.000255)						(0.000209)		
Y-Coordinate	6.37e-05							6.60e-05	
	(0.000168)							(0.000131)	

Table B1 (*continued*)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio	Yield-to-Permit Ratio
Surface Water	0.000912								−0.00502
	(0.00785)								(0.00710)
Constant	−383.2	446.7***	448.9***	444.5***	−140.6	447.9***	391.2***	171.9	447.8***
	(818.6)	(5.097)	(4.543)	(4.854)	(464.4)	(3.635)	(86.01)	(547.9)	(3.254)
Observations	10,749	11,898	11,898	11,898	10,749	11,898	11,898	11,898	11,898
R-squared	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
Number of Wells	2161	2391	2391	2391	2161	2391	2391	2391	2391

Note: Regression results using the yield (Gallons per Minute) divided by the decreed water right on the permit (Cubic Feet per Second). OLS regressions are between-effects allowing for the inclusion of time varying controls without picking a specific year. Robust standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

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